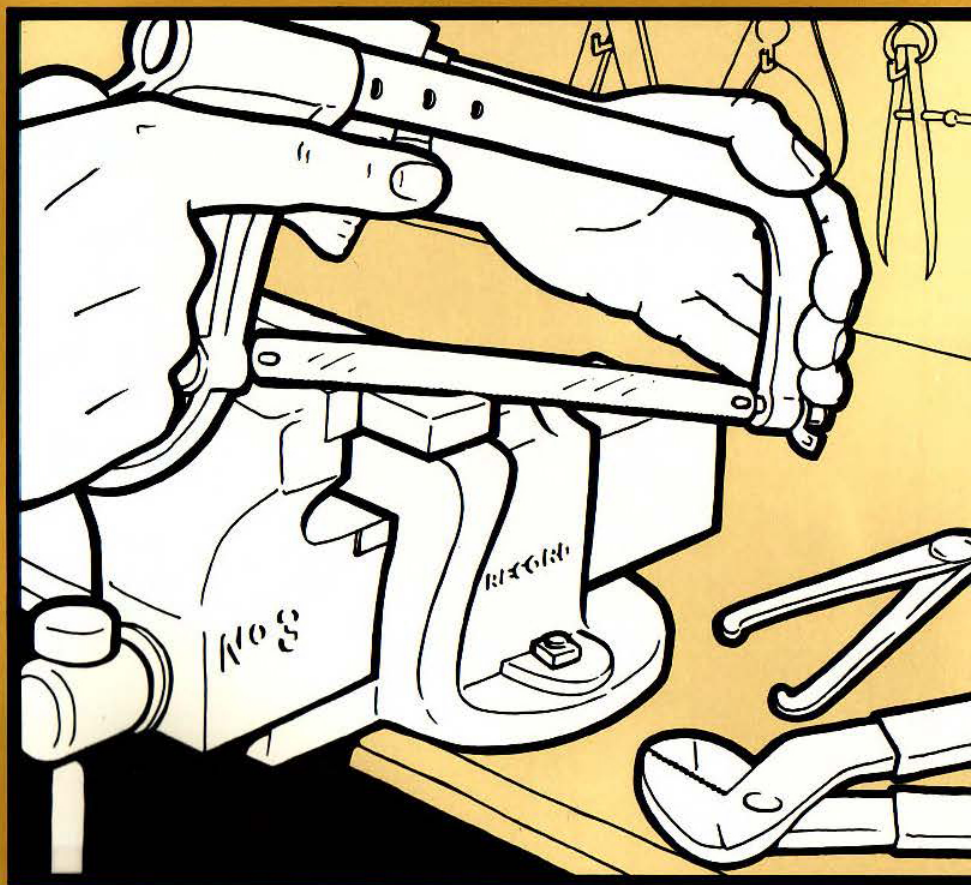


# BASIC BENCHWORK

LES OLDRIDGE



RKSHOP PRACTICE SERIES

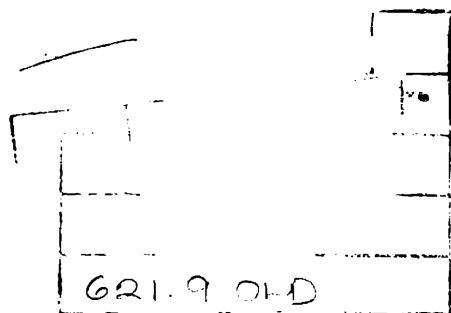
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# **Basic Benchmark**

Les Oldridge

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# CONTENTS

	Page
CHAPTER 1 Introduction	6
CHAPTER 2 Materials	8
CHAPTER 3 Reading engineering drawings	14
CHAPTER 4 Hacksaws	22
CHAPTER 5 Files and filing	25
CHAPTER 6 Hammers, chisels and punches	32
CHAPTER 7 Scrapers and scraping	39
CHAPTER 8 Measuring	44
CHAPTER 9 Marking out	53
CHAPTER 10 Drills and reamers	58
CHAPTER 11 Screwed fastenings, spanners, screwdrivers and pliers	69
CHAPTER 12 Taps and dies	79
CHAPTER 13 Riveting	86
CHAPTER 14 Soft soldering	91
CHAPTER 15 Silver soldering, brazing, bronze welding and engineering adhesives	97
CHAPTER 16 Welding	100
CHAPTER 17 Hardening and tempering tools	108
CHAPTER 18 Keys, keyways, splines, collars and shafts	112
CHAPTER 19 Sheet metalwork	118
APPENDIX	124
ACKNOWLEDGEMENTS	126
INDEX	127



# CHAPTER 1

## INTRODUCTION

Modern engineering workshops are equipped with machine tools capable of producing components to such accurate limits that hand fitting at the bench is no longer necessary. Mass production methods render the skills possessed by old-time fitters in danger of being forgotten for ever. This is a pity, as in many situations the ability to complete a job using only hand tools is a great asset. In any case it is often quicker to bring a component to the correct dimensions using a hand method than it is to spend time setting up the job in a milling machine or shaper, even if one is available.

Machine tools owned by the model engineer are often limited to a lathe and perhaps, a bench drilling machine, so he *has* to become skilled in the use of hand tools. The purpose of this book is to describe the basic skills he must acquire. It takes a great deal of practice to reach the standard required and although disappointment may be experienced at first, with the slow progress made, the satisfaction when the job is concluded is well worth the work involved.

It must be emphasised that no textbook, however comprehensive, can

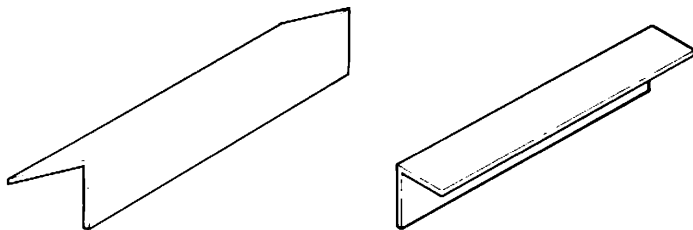
take the place of actual experience at the bench. The best advice is to 'have a go', perhaps on a bit of scrap material, to gain the necessary skill and confidence, before working on a valuable casting.

Throughout this book special emphasis will be made on safe working. In industry this is looked after by the Health and Safety at Work Executive but in the amateur's workshop there is no legislation to ensure the worker has a safe working environment. It is up to the individual to look after himself and to help to this end the various hazards likely to be encountered will be outlined from time to time.

A simple first aid kit, and the knowledge of how to use it, is desirable. A fire extinguisher is also a good investment and the Fire Protection Officer from the local fire brigade will be pleased to give free advice as to the best type to purchase to suit your particular needs.

If good work is to be produced a sturdy, rigid bench, fitted with a good quality vice, is essential. Most model engineers are not wealthy and setting up a workshop is a costly business. I hope to suggest, where possible, ways

**Fig. 1.1** Vice clamps bent up in aluminium, copper or lead, dimensions to suit vice.



of cutting costs without sacrificing quality. For example, good second-hand timber is often available at low prices, when buildings are being demolished, and a tactful word with the site foreman may provide just what is needed to build a bench at low cost.

Legs made from at least 3 in. square timber and the top from 2 in. deal planks should be aimed at. The space between the legs can be used to house a useful cupboard.

The size of the vice will depend on the type of work to be undertaken but it is better to have one a little larger than is thought to be necessary, to allow for 'future expansion', that is, for the bigger jobs which may come along later.

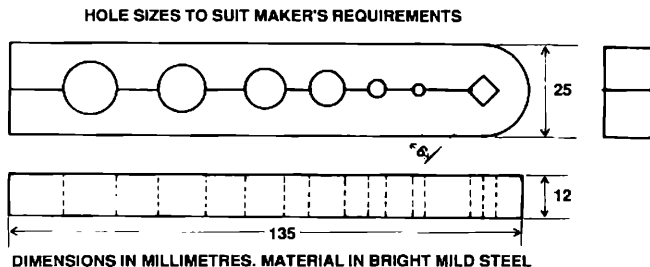
The height of the bench should be such that the top of the vice jaws are in line with the point of the user's elbow. This makes filing accurately much easier, but more about that later.

The vice jaws are serrated to prevent the work slipping when roughing down.

Clamps, sometimes called clams, to fit over the jaws are needed to prevent these serrations damaging finished surfaces. They may be made of lead, copper, aluminium or fibre or any other soft material. (See Fig. 1.1)

Various special clamps can be made to hold round or odd shaped work securely in the vice. Fig. 1.2. shows an easily made and useful device for holding round bar or pipe. Holes of a size to suit the bars in common use are drilled, as shown, in a piece of mild steel 25mm  $\times$  12 mm ( $\frac{1}{2}$  in.  $\times$  1 in.) and of a length to accommodate the number of holes required. A sawcut is made through the centre of all the holes, except the end one. A similar gadget for holding threaded material can be made in a like fashion, except that the holes are threaded before the gadget is split with the type of thread generally used. These two projects form a useful exercise after reading the chapters on hacksawing, drilling and cutting screw threads!

**Fig. 1.2** Vice clamp for holding round bars.



## CHAPTER 2

# MATERIALS

Before looking at the various tasks which are performed at the bench the materials on which we shall be working and their properties must be discussed. It is important that the most suitable material for the job in hand is chosen. Often this will be specified in the drawing from which we are working but sometimes we have to decide what to use.

The following properties then have to be considered:-

**STRENGTH.** The strength of a material is its ability to withstand stress without breaking. The load, or stress, may tend to stretch, compress, twist or cut the material. These are termed tensile, compressive, torsional or shear forces. See Fig. 2.1. The strength of a material varies with the type of stress to which it is subject. For example, cast iron has good compressive strength but relatively poor tensile strength; it is about four times stronger when it is squeezed than when it is stretched.

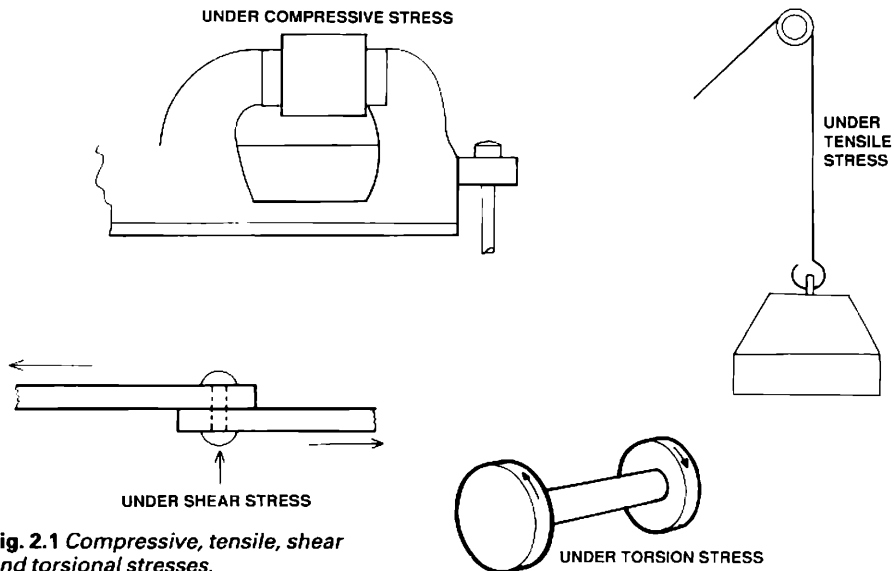
**ELASTICITY** is the ability of a stressed material to return to its original shape when the load is removed. Spring steel

has a high elasticity factor. Plasticine has practically no elasticity. Most materials are elastic below a certain limit, known as their elastic limit. If the stress applied exceeds this limit the material is permanently deformed.

**PLASTICITY** is the reverse of elasticity and is the property of a material to retain any deformation produced by loads after the load has been removed. Steel is plastic at red heat and can be forged to shape.

**DUCTILITY** is the ability in a material to be drawn out by tensile forces beyond its elastic limit without breaking. This property is important in the production of wire, the wire being produced by drawing metal through dies which get progressively smaller.

**MALLEABILITY** is a similar property to ductility except that the material is deformed beyond the elastic limit by compressive forces, such as rolling or hammering instead of by a tensile force. Lead is a malleable material but lacks ductility because of low tensile strength.



**Fig. 2.1** *Compressive, tensile, shear and torsional stresses.*

**BRITTLENESS** A material is brittle where fractures occur with little or no deformation. Glass is a classic example of a material with this property.

**TOUGHNESS** is the ability to withstand shock loads.

**HARDNESS** is the ability of a material to resist penetration, scratching, abrasion, indentation and wear. In the laboratory it is measured by applying a load to a small area of material by a hard steel ball or pointed diamond and measuring the depression made into the material under a given load. Chisels, lathe tools and centre punches, for example, must have this quality to do the job for which they are intended. Unfortunately the harder carbon steel tools are made the more brittle they become, so some hardness must be sacrificed for toughness in the tempering process. This will

be discussed more fully in the chapter on hardening and tempering.

**SOFTNESS**, obviously, is the opposite property to hardness. Soft materials may be easily shaped by filing, drilling or machining in a lathe, milling machine or shaper. In many cases the component is hardened by one means or another, to be discussed later, after the shaping process is completed.

## **MATERIALS**

Materials can be divided into a number of groups such as:

- (1) Metals, which can be subdivided into ferrous and non-ferrous metals. This is the group with which we are most concerned but the others will be met from time to time.
- (2) Plastics, which are now widely used in industry and which the model engineer will occasionally use.

- (3) Timber.
- (4) Ceramics – the name originally given to materials made from clay but now used to cover a wide range of materials.

## FERROUS METALS

These are the metals containing iron. Metals are rarely used in their pure state but are combined with other metals to form an ALLOY. In the case of iron, carbon is the most important addition. Although it is only present in small amounts it causes big changes in the property of the metal.

**CAST IRON.** In this form the iron has been melted and poured into a mould, usually made of sand, in which it is allowed to solidify. This is a simple, convenient and relatively cheap process to manufacture components of a complicated shape. Cast iron is an alloy of iron and carbon with small amounts of manganese, silicon, sulphur and phosphorus. It contains about 3% of carbon.

There are two types, grey and white. Both get their names from the appearance of the metal when fractured. In white cast iron all the carbon present is cementite; in grey cast iron most of the carbon is present as flakes of graphite and there is usually a remainder which is in the form of pearlite. Because cementite is intensely hard, white cast iron is hard and durable, though very brittle. Graphite is soft and is a good lubricant, so grey cast iron is readily machinable, less brittle and suitable for sliding surfaces. Being hard and brittle white cast iron is rarely used alone but it is the material used for the production of malleable iron.

**GREY CAST IRON**, then, is the type in common use; it is cheap and easy to cast and machine. As a typical example a motor car cylinder block contains 93.32% of iron, 3.3% of carbon, 1.9% silicon, 0.8% manganese, 0.14% of sulphur and 0.18% each of phosphorus, molybdenum and chromium. The carbon content of approximately 3.3% consists of about 0.7% of combined carbon and about 2.6% of free carbon.

Because of the free carbon content cast iron is easy to machine and file; the carbon flakes act as a lubricant, enabling the cast iron to be machined dry. Drilling or tapping of cast iron components is fairly easy, no lubricant being required. There is, however, a hard skin in which some of the moulding sand may still be present. This is particularly hard on lathe tools and when it has to be filed an old file should be used; a new one would probably be ruined.

Cast iron is used for model engine flywheels, internal combustion engine cylinders, model locomotive wheels and a host of other parts. Because of its self-lubricating properties it is an ideal material for plunger block bearings. The spindle of the *Model Engineer* sensitive drilling machine runs directly in cast iron bearings and shows little signs of wear after years of use.

Cast iron has low tensile strength and poor shock resistance.

## THE STEELS

There are British Standard Specifications for steels contained in BS 970 which dates back to 1942, but since that date there have been several revisions. In 1970 the specifications underwent a radical change and in 1983 the Standards were again restructured. Originally an EN code was used but this is

now replaced by a six digit system. It will be some time before the EN numbers disappear altogether and, in fact, some manufacturers show both the EN numbers and the current specifications where the two are closely aligned with only a point or two variation in analysis. For example, the free-cutting steel 212M36 corresponds to the old EN8M.

**PLAIN CARBON STEELS** The main difference between cast iron and steel is the carbon content. Plain carbon steel has never more than 1.5% carbon whereas cast iron, as has been stated above, has about 3%.

**MILD STEEL** containing about 0.15% to 0.3% carbon combined with the iron is ductile and malleable. It is easy to weld, machine, forge or press into a new shape. It may be worked hot or cold. Because of its low carbon content it cannot be hardened by heating and quenching, but can be case-hardened, a process which will be described later. It is supplied in bar form with hexagon, round, square or flat sections in a 'black' or 'bright' form and in sheets of varying thicknesses.

**MEDIUM CARBON STEEL** with a carbon content of 0.35% to 0.5% is much stronger than mild steel. Its hardness and strength can be increased by quenching the metal from a red heat. It can be tempered, rendering it suitable for many general engineering purposes where the stresses imposed are greater than could be withstood by mild steel.

**HIGH CARBON STEEL** with a carbon content of 0.55% to 1.5% is used for most tools after being hardened and tempered. Chisels, files, drills and reamers are made from this steel.

**ALLOY STEELS.** In order to improve the properties of steel and to suit the metal to special applications, other substances beside carbon are added to the steel. **NICKEL** improves the ductility and toughness of the metal. **CHROMIUM** and **MOLYBDENUM** increase its hardness while **VANADIUM** improves the elasticity, strength and fatigue resistance of the steel. All steel contains **MANGANESE** but sometimes more is added to improve the steel's mechanical properties.

**STAINLESS STEEL** is principally an alloy of iron, nickel and chromium. It has a high resistance to corrosion but in some forms it is difficult to machine. However, by introducing a free machining agent into the alloy this drawback can be overcome.

**SILVER STEEL**, the tool steel used by model engineers, is a carbon steel with 1.1% to 1.2% carbon, 0.35% manganese, 0.45% chromium and 0.1% to 0.25% of silicon.

**TINPLATE** Sheets of mild steel are coated with tin to provide the metal used for the familiar food containers and for many other purposes. It is a useful material for the model engineer, being easily worked and soldered and can be obtained without cost from discarded biscuit tins etc.

## **NON FERROUS METALS**

**ALUMINIUM** is the lightest of the commonly used metals. It is too soft to use in its pure state but alloyed with copper, magnesium and manganese it is widely used for many components. It is a good conductor of electricity but is impossible to solder by the usual methods.

**COPPER** is soft, ductile and of low tensile strength. It is an excellent conductor of electricity and is easy to solder or braze. It is the base of the brass and bronze alloys. Copper hardens with age and also work-hardens, that is it becomes hard when it is bent or stretched. It can easily be returned to its soft, ductile state by annealing. This is done by heating to a red colour and then allowing it to cool.

**LEAD** is soft, ductile and of very low tensile strength. It is often added to other metals to make them free cutting. It is typically used for lead acid battery plates and in soft solder.

**TIN** is corrosion resistant and is used to coat mild steel plate to make 'tin plate'. It is used in soft solder and is an alloying agent in bronze, and is the basis of 'white metal' bearings.

**BRASS AND BRONZE** When copper is alloyed with zinc, brass is formed. Bronze is an alloy of copper and tin and usually about 10% tin is used. Sometimes about 0.5% of phosphorus is added, the alloy then being called phosphorous bronze. There are various classes of bronze made especially for particular applications. It is for example, an excellent bearing material.

## **IDENTIFICATION OF FERROUS METALS**

Several metals have a similar appearance and new bar materials are often colour coded by painting the end with a distinctive colour paint. Often off-cuts are used up and it is essential that these are identified. Most model engineers have a scrap box and all sorts of odds and ends are stored there. Trouble will

be experienced if, for example, a piece of high carbon steel is selected when a free cutting mild steel is what is required. There are several ways in which metals can be identified and some tests appear below.

**Appearance.** Cast iron has a dark rough finish; the mould joint line is probably visible. A section of iron away from the skin has a grey appearance and a fracture appears crystallised.

Mild steel comes in two forms, black and bright. The former has a smooth scale with a blue/black sheen. The bright mild steel (B.M.S.) has a bright silver-grey surface. Medium carbon steel has a smooth scale and a black sheen while high carbon steel has a rougher scale.

**Grinding** A popular test is to grind the metal and note the colour, quantity and type of sparks given off. This is a difficult procedure to describe: a video film is really necessary, and it is equally difficult for the beginner to recognise the different types of sparks. It is suggested that an experiment is carried out using steels of known types and comparing the differences.

Cast iron gives off a short stream of red sparks which at some distance from the grinding wheel burst into a yellow spark formation. Plain carbon steel produces a lighter and brighter spark in a greater profusion than cast iron. As the carbon content increases the sparks become lighter, are in greater quantities and occur nearer the wheel. The high carbon steels produce secondary bursts bunching out from the primary sparks.

If materials are drilled it is very noticeable that the cuttings from cast iron are granular in form while those from steel come off in long spirals. The

cuttings (SWARF) from medium carbon steel may turn brown or blue, but still be in spiral form. Swarf is very sharp and can cause nasty cuts if handled, so special care is needed when clearing the cuttings away from a drill.

## **PLASTICS**

These materials become plastic above certain temperatures and while plastic they can be squeezed into dies or moulds to give them the required shape which they retain on cooling. There are two main types, THERMOSETTING and THERMOPLASTIC. The former group do not become plastic on re-heating. They are hard, rigid and rather brittle. They are used particularly for electrical equipment as they are good insulators. Bakelite comes within this category.

Thermoplastics may be softened by heat so they cannot be used at temperatures much above 100°C. Some of them, celluloid and Perspex for example, are transparent and most can be coloured by adding a suitable pigment. POLYVINYLCHLORIDE (P.V.C.) comes in

this class and is the flexible and rubber-like substance commonly used for insulating electric cables. POLYTETRAFLUORETHYLENE (P.T.F.E.) is similar to p.v.c. but has a very low co-efficient of friction which makes it particularly suitable for making bushes which need not be lubricated. NYLON, one of the earliest plastics, is used for a variety of purposes including small gearwheels.

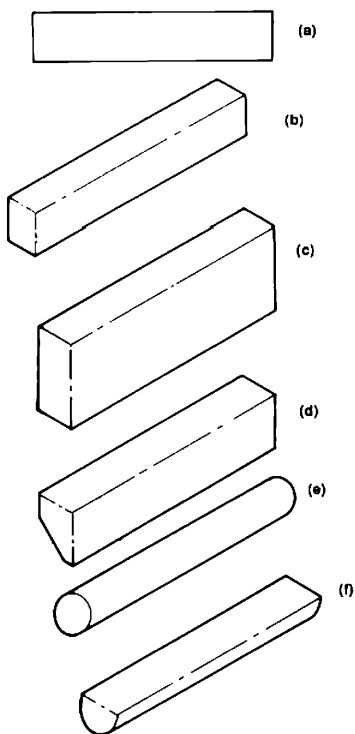
**REINFORCED PLASTIC.** Laminated plastic such as TUFNOL consists of a fibrous material such as paper or woven cloth impregnated with phenolic resin. The sheets of fabric are then laid up in an hydraulic press and squeezed and heated so that they become solid sheets, rods or tubes.

**GLASS FIBRES** can be bonded together by polyester or epoxy resins to form large and complex mouldings. Crash helmets and boat hulls are examples of things made in this way. The customary term is "glass-reinforced plastic" or g.r.p.



## CHAPTER 3

# READING ENGINEERING DRAWINGS



**Fig. 3.1** View (a) could be any of the other shapes – viewed from above.

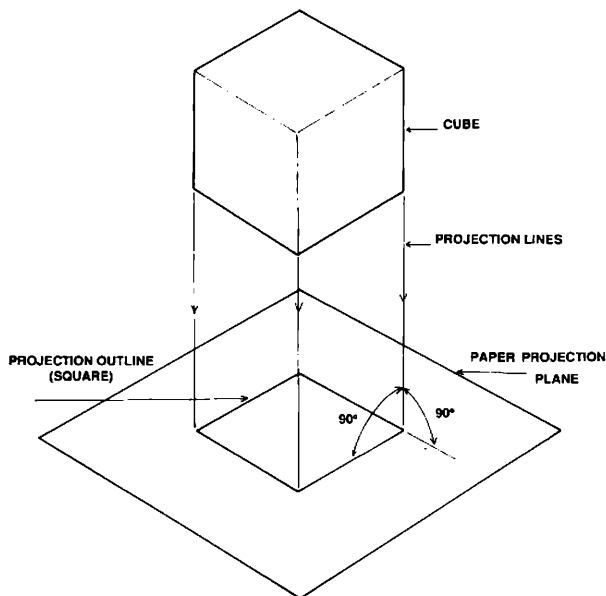
A fitter working at a bench will normally be required to produce components to the dimensions and outline as shown on an engineering drawing so, quite obviously, he must be able to read drawings of this kind. Although it is not intended to study this complex subject at any great depth, certain fundamentals will be explained, sufficient it is hoped to allow the tyro to interpret drawings which he has to work from.

While the main details of a simple part can be shown in a pictorial view, for sufficient information to be available to construct the average component, several related views showing the front, sides, top and/or bottom are required. For example, the single illustration shown in Fig. 3.1 could be an illustration of any of the shapes shown below.

For all the details required to make all but the simplest of components, drawings using **ORTHOGRAPHIC PROJECTION** are needed. There are two systems, **FIRST ANGLE**, widely practised in the U.K., on the Continent and in the U.S.S.R., and **THIRD ANGLE**, mainly used in America but occasionally in Britain.

Orthographic projection results when the outline of an object is projected, at

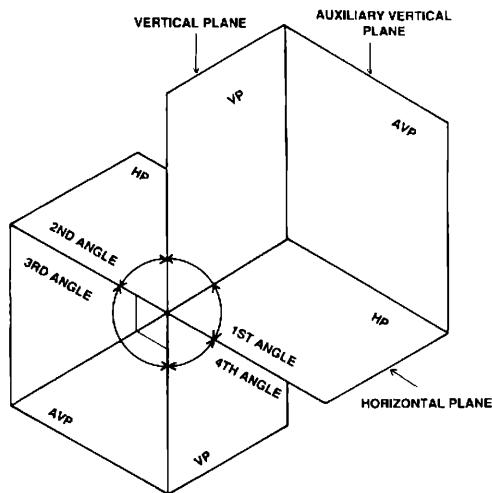
**Fig. 3.2**  
*Perpendicular  
orthographic  
projection.*

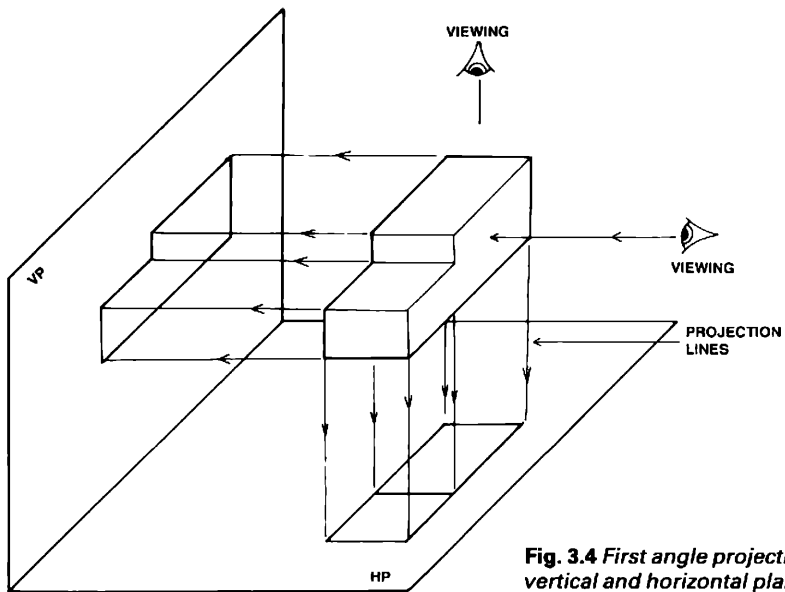


right angles, on to a flat surface known as a plane. See Fig. 3.2 where lines have been projected from a cube, downwards on to a flat surface.

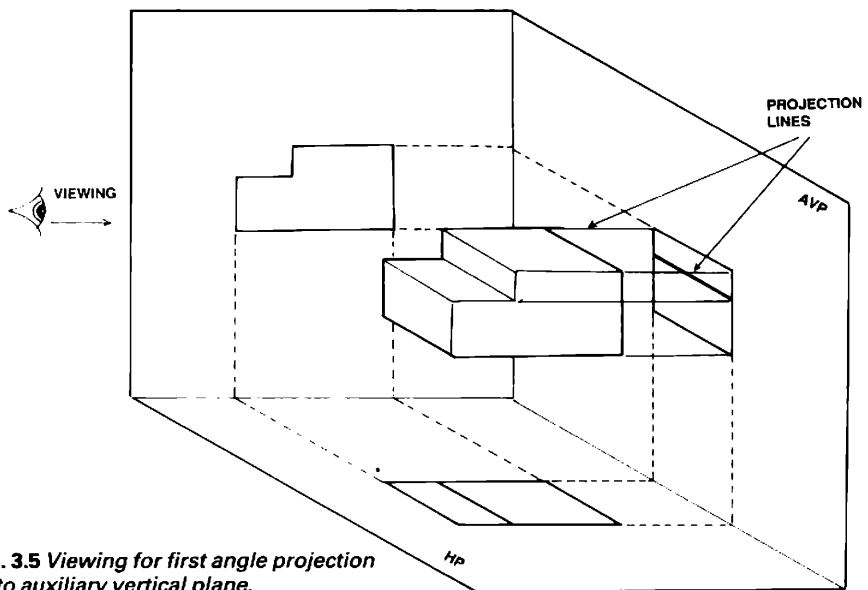
The projection plane can be vertical or horizontal and these are called the principal planes of projection; they are termed the H.P. (horizontal plane) and

**Fig. 3.3** *Principal  
planes of  
projection.*

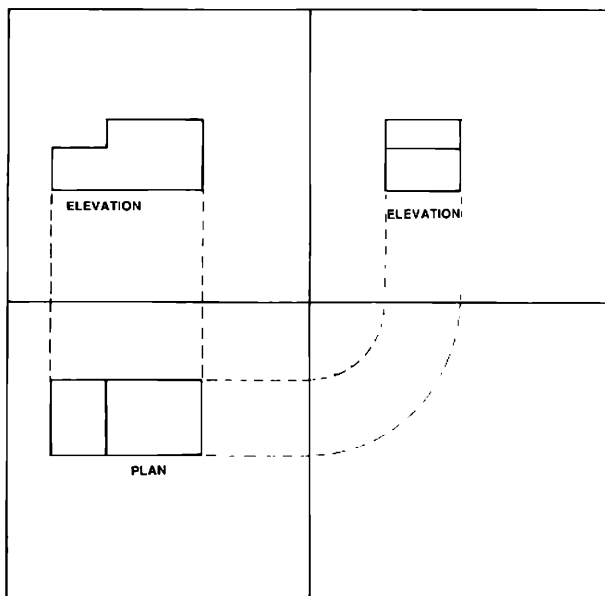




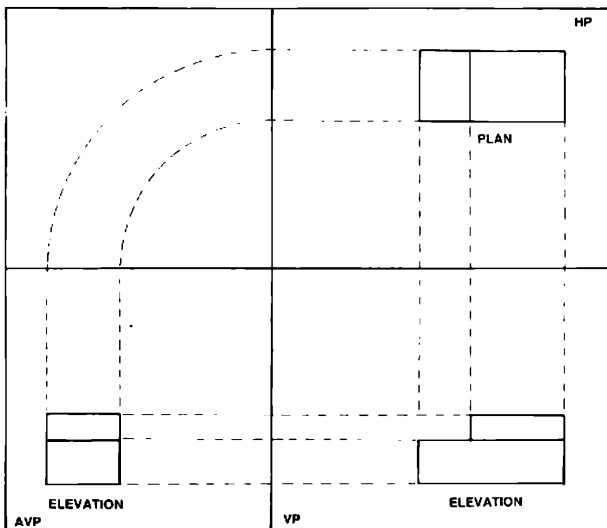
**Fig. 3.4** First angle projection onto vertical and horizontal planes.



**Fig. 3.5** Viewing for first angle projection onto auxiliary vertical plane.



**Fig. 3.6** When 'box' is opened out drawing in first angle orthographic projection will look like this.



**Fig. 3.7** The same component as above now drawn in third angle projection.

### V.P. (vertical plane)

The two systems of first and third angle take their names from the first and third quadrants of a circle. (See Fig. 3.3) Here four open ended 'boxes' are shown around the quadrants of a circle. Objects to be drawn are imagined to be placed in one of these 'boxes' and their outlines projected on to the 'walls' of the 'box'. First and third angle projections have similar merits; only local preference makes one more popular than the other.

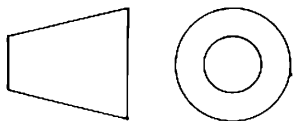
**FIRST ANGLE ORTHOGRAPHIC PROJECTION.** In Fig. 3.4 perpendicular lines have been projected from an object on to the horizontal and vertical planes in a first angle situation. If the horizontal plane is swung down to the vertical plane two orthographic views are obtained, an elevation and a plan. A third outline can be viewed and projected on to an auxiliary vertical plane (A.V.P.) as shown in Fig. 3.5. If this plane is swung through  $90^\circ$ , so that it is in line with the other vertical view, the three together give a plan and two elevations of the object, as shown in Fig. 3.6. Generally these three views will give sufficient detail for a component to be made but there is no reason why other views (up to six) cannot be projected in the same way to disclose further details.

**THIRD ANGLE ORTHOGRAPHIC PROJECTION.** Going back to Fig. 3.3, if lines are projected from an object placed in the third angle position on to the horizontal and vertical planes, outlines will appear exactly as viewed. If the sides of the 'box' are then straightened out, as was done in the first angle exercise, then two elevations and a plan will result, as shown in Fig. 3.7. It will be seen that the plan view now appears in the right hand top section and the two elevations in the lower half of the paper.

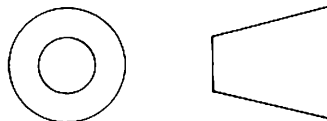
Both systems of projection have their own international symbols by which their use can be recognised. The symbols are similar to two views of the frustum of a cone. (See Fig. 3.8a and b).

**CONVENTIONAL SYMBOLS** In more leisurely times, when labour was cheap, engineering drawings were completed in great detail, every thread on every bolt was shown, every rivet was drawn, but now drawings are very much simplified to save the draughtsman's time. Conventional symbols are used for common features such as bolts, studs and equally spaced holes. Those which are likely to concern bench workers appear in Fig. 3.9.


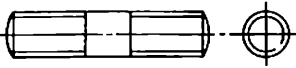
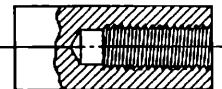
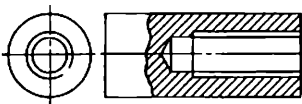
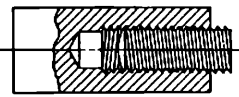
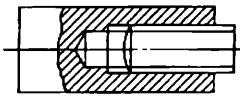

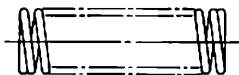

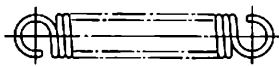
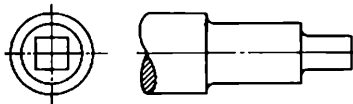
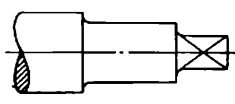
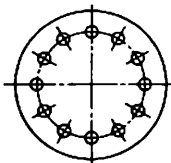
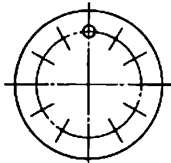
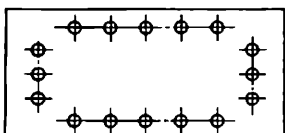
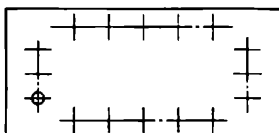
**HIDDEN DETAILS** are shown by short dashes. Fig. 3.10a shows holes in a bar indicated in this way. This sketch also



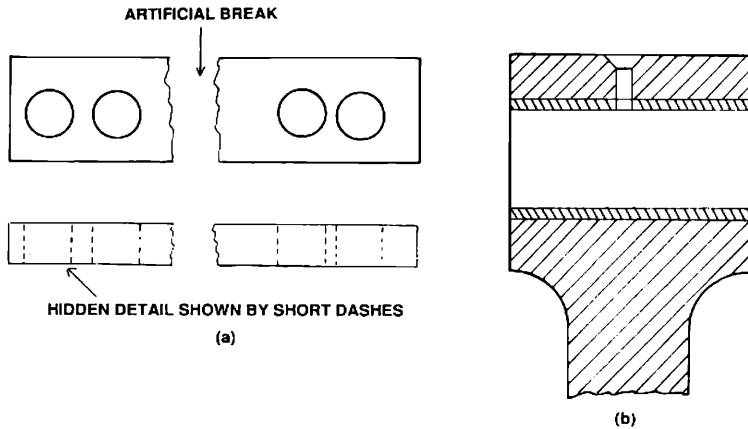
**Fig. 3.8a** Symbol for first angle projection drawing.



**Fig. 3.8b** Third angle projection drawing symbol.

TITLE	SUBJECT	CONVENTION
EXTERNAL SCREW THREADS (DETAILS)		
INTERNAL SCREW THREADS (DETAILS)		
SCREW THREADS (ASSEMBLY)		
COMPRESSION SPRINGS		
TENSION SPRINGS		
SQUARE ON SHAFT		
HOLES ON CIRCULAR PITCH		
HOLES ON LINEAR PITCH		

**Fig. 3.9** Conventional symbols.



**Fig. 3.10.**

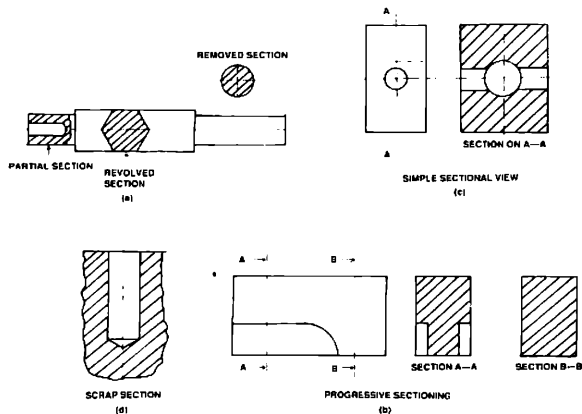
shows how, when a component is too long to accommodate on the paper but is of uniform section, an artificial break is indicated.

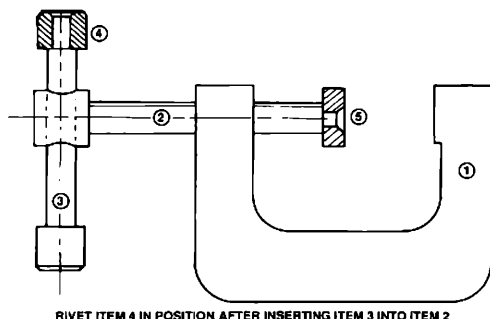
**SECTIONED VIEWS** are views in which it is imagined that the components have been cut through to show their internal construction. Such views are indicated by diagonal lines called hatching lines. Fig. 3.10b shows a connecting rod small end showing the bush, probably made

of phosphor-bronze, and the hole for lubricating purposes. The hatching lines are generally at 45° to the centre line of the component. On sectioned features which are adjacent to one another the hatching lines are drawn at opposite angles.

Sometimes it is necessary for a drawing to contain a special sectional view of a component to make its shape abundantly clear; several examples are given in Fig. 3.11. Illustrations (b) and

**Fig. 3.11 Various sectional views.**





ITEM 5 TO BE RIVETED  
IN POSITION AFTER  
SCREWING ITEM 2 IN  
POSITION; ALLOWING  
ITEM 3 TO TURN  
FREELY ON ITEM 2

ITEM NUMBER	DESCRIPTION
1	FRAME
2	SCREW
3	HANDLE
4	FERRULE
5	PAD

RIVET ITEM 4 IN POSITION AFTER INSERTING ITEM 3 INTO ITEM 2

Fig. 3.12 Assembly drawing of G-clamp.

(c) show sectional views where the direction of viewing is shown by arrows. There are several examples of centre lines in these drawings and it will be seen that they consist of a chain line, a long thin line followed by a short one.

Usually a component is shown in an

ASSEMBLY DRAWING, where it is depicted with all its pieces assembled, and a DETAILED DRAWING where each single part is shown. An assembly drawing of a 'G' clamp is shown in Fig. 3.12 and a detailed drawing of the same component in Fig. 3.13.

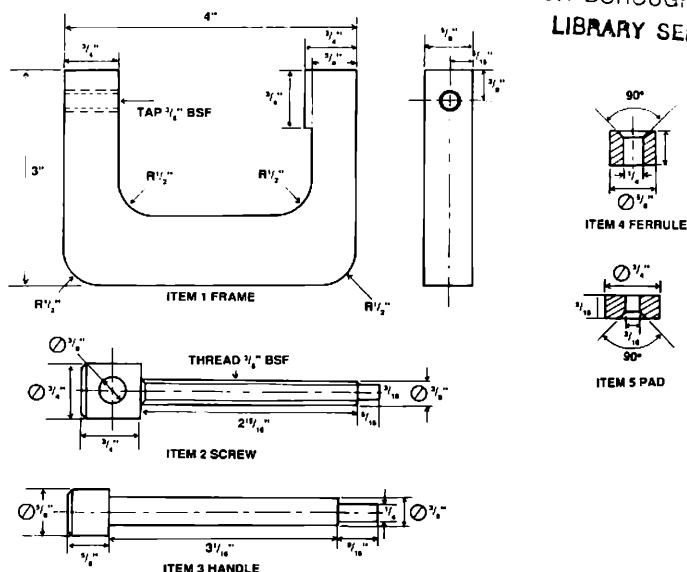


Fig. 3.13 Detail drawing of G-clamp. All items in B.M.S.



## CHAPTER 4

# HACKSAWS

You will often have to cut off a piece of metal to a prescribed length, using a hacksaw. The hacksaw, then, is an essential tool in an engineer's workshop, but it is often neglected, misused or used with a blade which is not correct for the particular job in hand.

Hacksaw blades are classified by their degree of flexibility and how many teeth they have to the inch. High speed steel 'all hard' blades are designed to give the optimum cutting performance on all types of materials but they are easily broken if misused. A famous maker describes them as the professional blade suitable for the man who

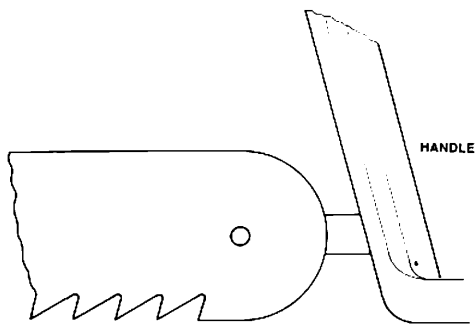
takes a pride in his work and knows exactly how to use them. They can only be used where the workpiece is firmly held.

Probably more suitable for the model engineer is the bimetal high speed blade which consists of a high speed cutting edge electron beam welded to a tough alloy back. The makers claim that this blade is virtually unbreakable in normal use and is, therefore, safe in less experienced hands.

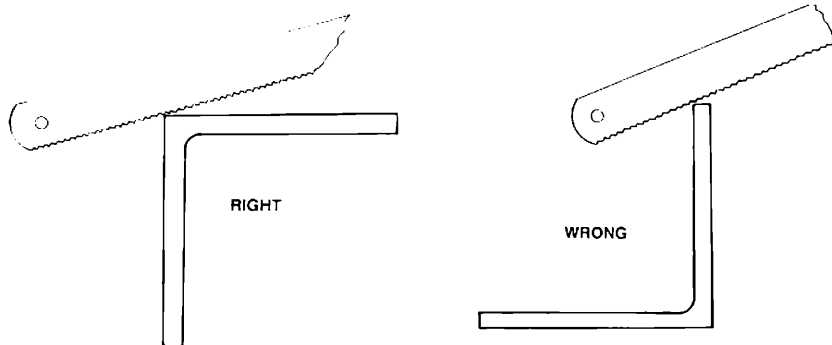
There are also flexible blades particularly suitable for work by trainees and occasional use by unskilled workers.

The number of teeth per inch on blades varies from fourteen to thirty-two. The expense involved will preclude the model engineer from stocking the whole range and some with eighteen and some with twenty four teeth per inch will probably meet most of his needs.

The number of teeth on the blade to be used depends on the material to be cut and its thickness. As a general rule three consecutive teeth must be in contact with material being cut. If thin tubing or sheet has to be cut then a blade with thirty-two teeth per inch is desirable.



**Fig. 4.1** Teeth must point forward away from handle.



**Fig. 4.2** Cut should be started with as many teeth as possible in contact.

The blade must be fitted to the frame with the teeth pointing forward, that is away from the handle, see Fig. 4.1. The tensioning wing nut must be turned to take up the 'slack' and then tightened three full turns. Correct tension of the blade is important. If the blade is loose it will buckle and not cut straight; if it is too tight an unnecessary load is placed on the blade ends and damage to the blade or the frame may result.

The metal to be cut must be securely fastened in the vice. When starting the cut the thumb of the left hand can act as a guide to position the blade, very short strokes with light pressure being applied. Do not start the cut on the short edge of the workpiece but allow as many teeth as possible to be in contact with the work. Fig. 4.2 shows the right and wrong way to start a cut on a piece of angle iron. The wrong method might result in stripped teeth. When the blade has entered the work the left hand is transferred to the front of the frame and long steady strokes applied.

Fig. 4.3 and Fig. 4.4 show the incorrect and correct method of holding work in the vice so that as many teeth as possible are in contact with the work.

Sixty strokes a minute is the correct

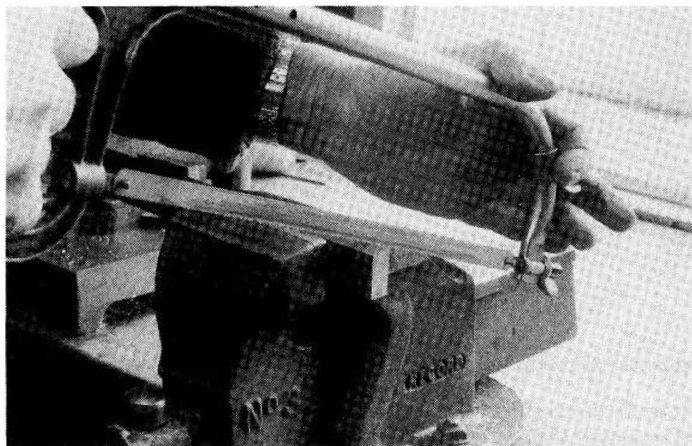
speed for low speed alloy blades and seventy for high speed ones. Nothing is gained by increasing the speed: strokes using the full length of the blade give the best results and are less tiring. The beginner is very inclined to saw much too fast.

A new blade should not be used in a cut previously made by a worn one as the old cut will be narrower than the one that the new blade will cut. If a new blade is used in the existing cut it will jam and could easily break. If a blade breaks partly through a cut the work should be turned over and the cut started from the other side.

Care is necessary when the saw reaches the end of its cut. Pressure and the rate of stroke should be reduced. Neglecting this precaution can result in injury to the hands and a broken blade.

Keeping a cut straight will come with practice; not too much pressure, a correctly tensioned blade and long steady strokes all make for accurate work. Cutting carefully to a scribed line will save a lot of tedious filing necessary to bring a job to the prescribed dimension and to correct the error made in the sawing.

Hacksaw blades can be obtained in several different lengths and a 12 in.

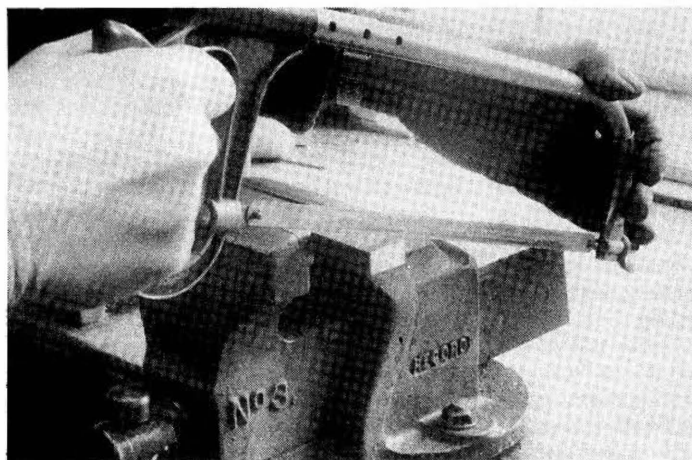


**Fig. 4.3 INCORRECT.**  
*Work held in vice so  
 that narrow side is in  
 contact with the  
 hacksaw teeth.*

blade is recommended for general use. Hacksaw frames are generally adjustable to allow different length blades to be used.

Junior hacksaws, a small edition of the one already described, are often used by the model engineer for small delicate jobs. Light and easy to handle, they form a useful addition to the tool kit.

As is common with all types of saws the teeth of hacksaws are set to the sides. This causes the blade to cut a slot wider than itself and prevents the body of the blade rubbing or jamming in the sawcut. Often alternate teeth are set to right and left, every third or fifth tooth being left straight to break up the chips and help the teeth to clear themselves.



**Fig. 4.4 CORRECT.**  
*Wide side of work  
 presented to the  
 hacksaw teeth.*

## CHAPTER 5

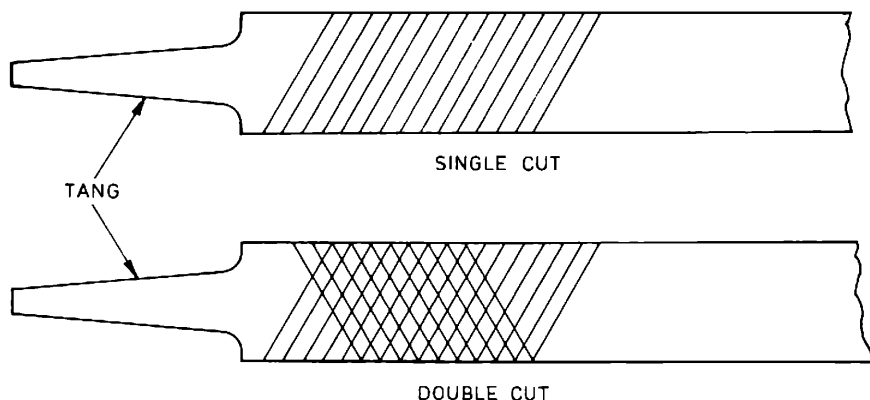
# FILES AND FILING

Filing is a skill which must be developed by the model engineer but, unfortunately, a lot of practice is required before the average beginner can become really proficient and be able to file a flat surface. Nevertheless once the knack has been acquired the operation becomes automatic and one files flat without thinking about it.

Files are classified according to their length, section and cut. There are many different types but the model engineer only requires a few. Exactly what he needs depends on the type of work on

which he is engaged. I have found it a good policy, with all hand tools, to buy them as the need arises, rather than purchase several at the same time on the off-chance that they will come in handy in the future. This policy spreads expenditure evenly and ensures that only essential tools are purchased.

**File length** The length of a file is measured from the shoulder above the tang to the point. Needle files are the exception to this rule, the total length being measured.



**Fig. 5.1** Single and double cut files.

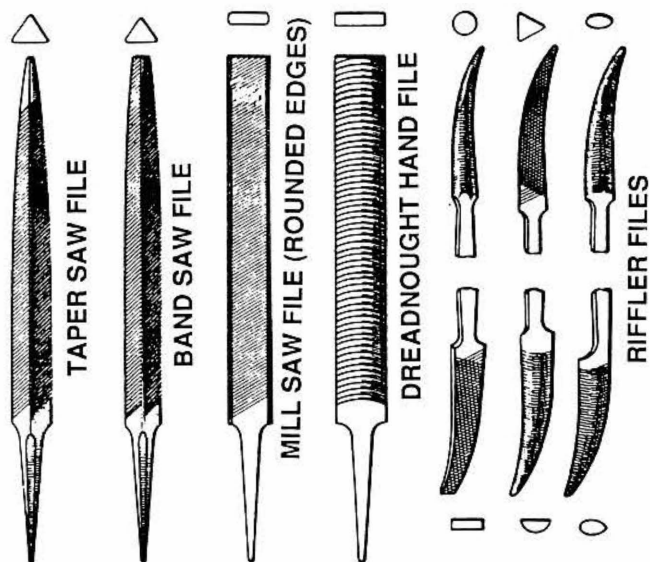
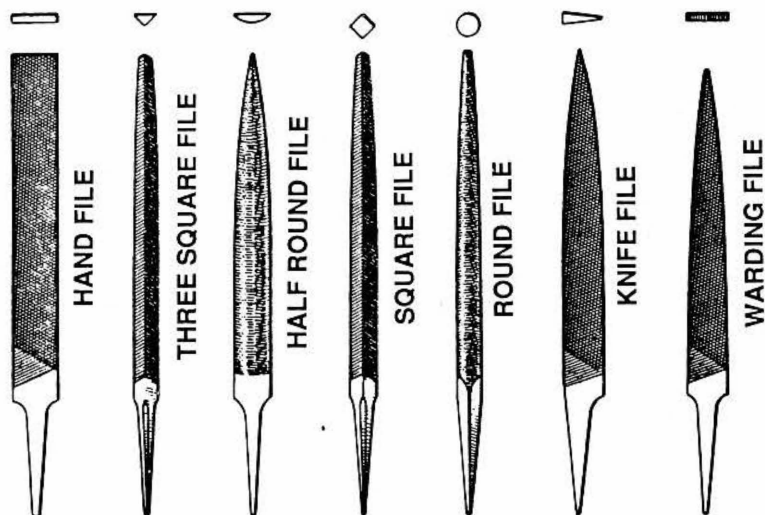


Fig. 5.2 Common types of files.

**File cut.** A file may have a single or double cut. In single cut files the teeth are parallel to one another and at an angle to the centre line of the file. The double cut file has a second cut over the first. This produces small pyramid-shaped teeth which have more cutting edges. It is the double cut file which is in common use. See Fig. 5.1.

Files may be cut with teeth of the following grades: Rough, Bastard, Second Cut, Smooth and Dead Smooth. Those in general use and likely to be found in the model engineer's workshop are the bastard, for the heavy removal of material but leaving a fairly rough finish, the second cut, a general purpose file for light removal giving a fair finish, and the smooth for fine finishing work.

Two rather special cuts should be mentioned, the Dreadnought for the rapid removal of soft metal such as aluminium and the Rasp which will deal, in a rough and ready sort of way, with wood.

**File Sections** There are several different file sections available to cope with different kinds of work. Fig. 5.2 shows the shape and section of a variety of files.

The **HAND FILE** is parallel throughout its length, viewed from the cutting face, but its thickness tapers towards the end. Both faces are double cut and one edge is single cut. The other edge is left smooth and forms a 'safe' edge. This allows cuts to be made into corners without damaging the side against which the 'safe' edge is in contact.

The **FLAT FILE** is tapered in both width and thickness and is double cut on both faces and single cut on its edges. It is a very useful general purpose tool.

The **HALF ROUND** is another useful

shape, but misnamed; its section is not half round but only a segment of a circle.

**SQUARE FILES** are double cut on all four faces and are tapered for the first third of their length. They are useful to clear small corners and slots and to form square holes.

**THREE SQUARE** or triangular files are the speciality of the 'saw doctor' but are also useful for shaping holes with less than right-angle corners and for producing really sharp corners.

The **ROUND FILE**, colloquially known as the 'rat tail', for obvious reasons, is tapered for the first third of its length. It is used for enlarging holes and comes in a variety of sizes. Buy one to suit your particular needs; I find one with a diameter of about 6 mm ( $\frac{1}{4}$  in.) to be the most useful size.

**WARD FILES** are similar in shape and cut to the flat files but are much smaller. They are of uniform thickness throughout their length. Originally intended for use by locksmiths for producing wards in keys and locks, they are useful for dealing with the small components commonly found in the model engineer's workshop.

The **KNIFE FILE** is wedge shaped and not in general use but is useful on occasions in entering and enlarging slots where standard files are unsuitable.

**NEEDLE FILES** are very small files of various shapes and sections which are used for very fine and delicate work. The tang is formed into a thin cylindrical shape and the pitch of the teeth range from 40 to 200 teeth per inch.

**RIFFLER FILES** are specially shaped to meet special requirements. They are, for example, used when tuning internal combustion engines to smooth the exhaust and inlet ports.

## USE OF FILES

Files must never be used unless the tang is protected by a handle. The handle must be firmly attached to the tang and be a comfortable fit in the hand. Failure to fit the handle properly, or using a file without a handle, can lead to the tang being forced into the palm of the hand, causing a nasty injury. To fit the handle the file should be held upright on a wooden bench or block of wood, tang uppermost, and the handle tapped firmly in position. The tang should extend well into the handle. The file itself must not be hammered. Files are dead hard and in consequence rather brittle. Any hammer blows are likely to cause chips to fly off the file, causing injury to anyone nearby and damage to the face of the hammer.

The beginner should learn the art of filing by practising on odd pieces of scrap metal, mild steel or cast iron about two inches square in section being most suitable. A partly-worn flat file should be used at first as a new file is too sharp at this stage and in any case it is better reserved for use on brass or bronze before being taken into use on iron or steel.

The correct stance at the bench is just as important when filing as it is for sportsmen when playing golf or cricket. The handle of the file should be held comfortably in the right hand and the left hand should grip the extremity of the blade with the fingers pointing downwards. The left foot should be placed well forward and the right foot turned slightly outwards. The body should be well balanced and one should feel comfortable. If you are left-handed reverse the above instructions.

The file should be placed firmly on the work and moved forward with a firm steady stroke. Every endeavour

must be made to keep the movement in a horizontal plane, keeping even pressure on both ends of the file. Beginners nearly always rock the file so that the surface produced becomes curved instead of flat.

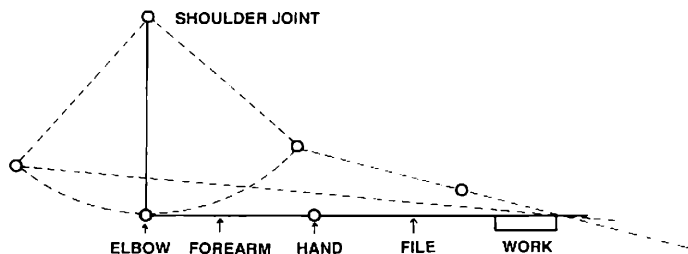
If the upper arm is considered as a lever, pivoted at one end at the shoulder joint and the other end at the elbow, it will be seen in Fig. 5.3 that if the shoulder is kept rigid the elbow moves in an arc. Unless a positive effort is made to correct the movement of the file it will rock, giving rise to a convex surface on the workpiece which must be avoided.

A full stroke should be made with the file, in fact the stroke should only finish as the handle approaches the work. The file should then be drawn back, the pressure having been released. The file only cuts one way, the teeth being formed to cut on the forward stroke only.

The jaws of the vice in which the work is held should be level with the user's elbow. This is helpful in keeping the movement of the file horizontal. The work should be held securely in the vice. If the workpiece has a finished surface, or is soft, the clamps described in Chapter 1 should be used to prevent the serrations in the jaws of the vice causing damage.

Choose the right file for the job, use as big a file as is practicable, do not nibble at the job with a small file. Use a bastard file if a lot of metal has to be removed, then a second cut one. A smooth file may be used, as the work is brought to size, if a fine finish is required.

Files are commonly used at too fast a speed. A file is a cutting tool and being made of carbon, not high speed, steel, the correct cutting speed is quite low. It is difficult to give a hard and fast rule for



**Fig. 5.3** Positive effort needed to prevent file rocking.

the stroke rate for filing as there are many variable factors – the material being worked, the type of file being used and the strength and experience of the worker all have to be considered. An average speed of around sixty to seventy strokes per minute is about right.

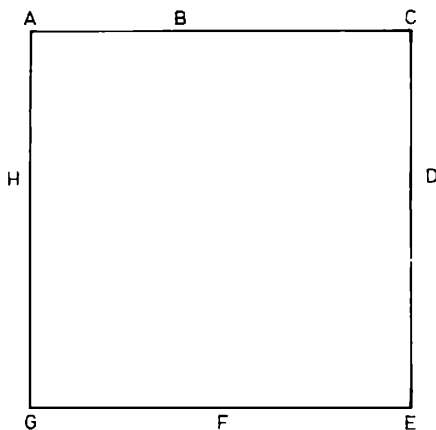
Keep checking the work with a straight edge and/or a square. Do this early and often so that if an error is creeping in it can be detected while there is enough metal left for a correction to be made.

By changing the direction in which the file is working it is possible to check how the metal is removed by watching the marks made by the file. Fig. 5.4 shows a square piece of metal. If the file is used on the square from F to B a set of file marks will appear at right angles to G – E. If the file is now used from E to A it will be found that the original marks will not be completely obliterated and it can be seen where the low spots are and the necessary corrections can be made. The file can then be used from G to C when a fresh sets of marks will appear. By constantly changing direction of the strokes of the file in this way and by frequent checking of the work with a square and/or straight edge accurate work can be produced. Slow

steady strokes with an even pressure will remove the metal at a good rate.

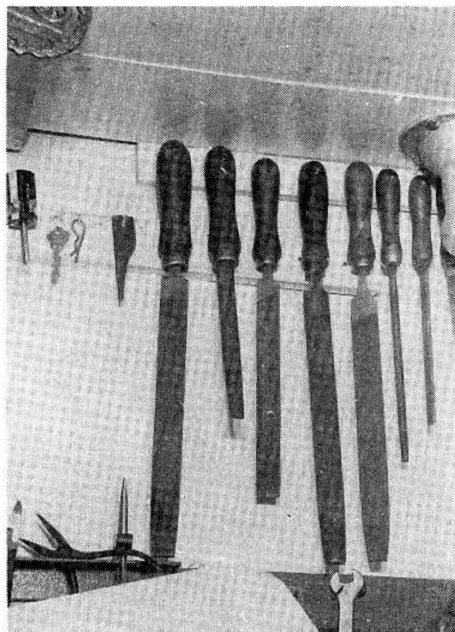
Use new files for such metals as brass and bronze and when they have become dulled they can be used effectively on cast iron and steel. Very old files should be used on castings where there may still be traces of the moulding sand which will spoil a new file. Avoid using files on sharp edges.

Files are expensive and pay for looking after. If they are thrown in a drawer with other tools there is a danger that their teeth will be damaged. Hang the files on a rack; holes drilled in the



**Fig. 5.4**





**Fig. 5.5** Files hung on nails on a rack after holes have been drilled in their handles.

handles allow them to be hung on nails on a rack as is shown in Fig. 5.5.

Files should be regularly cleaned with a file card. This is a brush composed of stiff wire bristles woven on to a strong canvas. The canvas is nailed to a suitable wooden block which forms a handle. The file blade should be brushed crossways with the card. This should not be done too vigorously so that the hard bristles blunt the file teeth. 'Pinning' occurs when a piece or pieces of metal lodge between the teeth of a file, causing scratch marks to appear on the surface of the work on which it is being used. If the offending metal can-

not be removed by the file card in the ordinary way it can be scraped out with a piece of pointed metal, being careful not to damage the teeth. Problems with pinning may be alleviated by rubbing chalk into the file but this should not be done when filing cast iron or brass as it causes the metal to glaze under the file.

File marks may be removed by **DRAW FILING**. For this purpose a fine cut file is used crossway on the work, as is shown in Fig. 5.6. The file is grasped by the handle and tip and propelled forwards and backwards. The teeth of the file do not cut so harshly when it is used in this way.

Although filing in the lathe is not strictly bench work it must be considered. This practice does not find favour in some quarters, it being held that any finish required should be obtained by the lathe tools. However, the makers of Stubs files make particular mention in their User's Handbook of filing in the lathe and undoubtedly in some circumstances it is justified. They give the following advice:

'When work to be filed is revolving in the lathe, the file should be used with a stroking action allowing it to glide slightly along the work. This will help to avoid making ridges and will help keep the file clear of chips. Because of their sharpness, new files are best avoided for lathe work where a fine finish is required. Lathe work should not be touched by hand as oil and moisture can coat the surface and it is then difficult for the file to hold.'

There is some danger in filing in the lathe. Particular care must be taken to see there is no loose clothing likely to catch in the revolving chuck or work. Sleeves must be rolled up or tightly fastened at the cuff.

In order to produce a fine finish on



**Fig. 5.6** *Draw filing.*

work which has been filed various grades of emery cloth are used. Emery cloth is obtainable from coarse grades right down to very smooth ones and any of them is best used with an old file or a piece of wood as backing. If an especially fine finish is required a thin oil or paraffin on the emery cloth will assist. Worn-out coarse emery cloth should not be discarded but can be

used as a fine grade.

Care must be taken, when using emery cloth, to ensure that the accurate work produced by the file is not spoilt. Sharp corners can be rounded off by the careless use of emery paper.

Copper and its alloys can be given a high degree of polish when smooth by the use of a metal polish, such as Brasso.

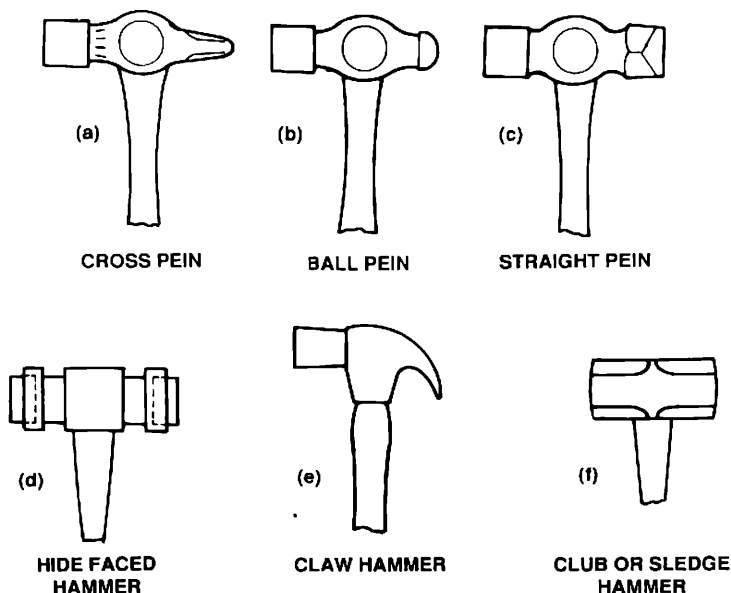
## CHAPTER 6

# HAMMERS, CHISELS AND PUNCHES

The term 'He is a hammer and chisel merchant' is sometimes used in a derisory way to infer a workman is a bit of a bodger, prone to using brute force when something does not quite fit. Yet to use a hammer and chisel properly is

a highly developed skill, only achieved after long practice.

Hammers come in a variety of shapes and weights. Engineer's hammers are known by the shape of the end opposite the striking face, the PEIN. The BALL



**Fig. 6.1** Common types of hammers.

PEIN, illustrated in Fig. 6.1b, is the most common type, the ball-shaped end being used mostly for riveting over the ends of rivets and pins. Cross and straight peins are useful for striking blows in awkward places.

The HIDE FACED hammer, shown in Fig. 6.1d, has a hollow cylindrical steel centre into which is pressed leather, or some similar material. In cases where blows are required on finished or semi-finished surfaces the use of this type of hammer avoids damage. A plastic material is now often used for the striking face.

The CLUB HAMMER shown in Fig. 6.1f and the CLAW HAMMER in Fig. 6.1e are not really engineer's tools. The claw hammer is a carpenter's tool. Instead of the pein described in the other types it has a claw with a slot for drawing out nails. The club hammer is a mason's tool, but a larger hammer of this type, with a long handle, is known as the sledge hammer and is used by blacksmiths and on heavy engineering work. In use, when blows are struck, the shaft is held in both hands.

Hammer shafts are generally made of hickory. A slot is cut in the thin end of the shaft and this end is forced tightly into the hole in the hammer head. A steel wedge is then driven into the slot in the shaft, expanding it, so that it is a tight fit in the hammer head. It is important that this tight fit of the shaft on the hammer head is maintained. A head which is loose is likely to fly off when the hammer is in use, causing injury or damage to persons or things in the immediate vicinity.

Engineers' hammer heads vary in weight from 0.125kg (about 4 ounces) to 1.5kg (roughly 3½lbs). Sledge hammers are made up to 14 lbs. The lighter hammers are used for the more delicate

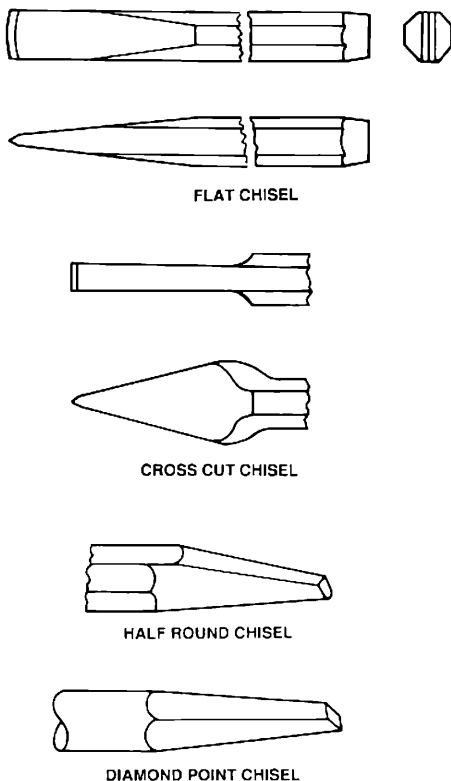


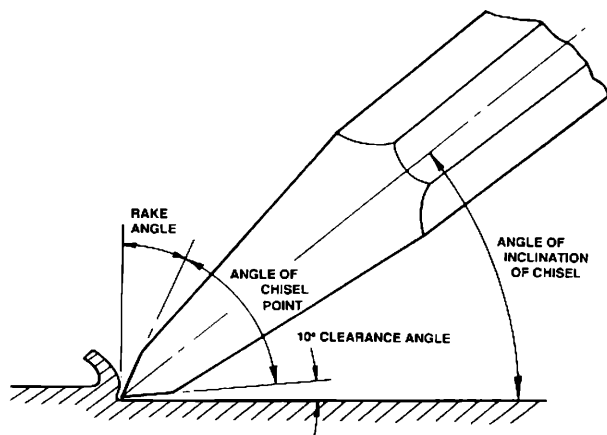
Fig. 6.2 Types of chisels.

jobs but it is a mistake to use one which is too light. As experience is gained it becomes an easy matter to pick the correct weight for the particular job in hand.

### CHISELS.

The cold chisel is a valuable tool for all sorts of reductions, alterations and fitting of parts. Although now generally replaced by improved machine tools they still have a place in every tool kit. They are called 'cold' chisels because they are used for work on metals in

**Fig. 6.3** *Cutting with a chisel.*



their cold state. This is to distinguish them from tools which are used when working metals in a hot condition, such as in blacksmith's work.

While the scraper, discussed in the next chapter, is used for the removal of small amounts of metal to make a precision fit, chiselling is the quickest way to remove metal by hand, but accuracy is not very high and surface finish is poor. It is basically a primary treatment before finishing off work with a file.

The various types of chisels are shown in Fig. 6.2. The **FLAT CHISEL**, the most common type, is used for surfacing and cutting off, the **CROSS-CUT** for roughing and grooving and the **DIAMOND** for similar purposes. The **HALF ROUND** is particularly useful for cutting oilway grooves.

The action of cutting when using a chisel is shown in Fig. 6.3, the angles of rake and clearance being clearly shown. These angles depend on the angle of inclination of the chisel; if the angle is increased then the clearance angle is also increased but the rake angle becomes less. For general use a chisel

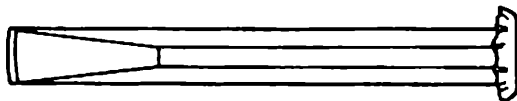
point is ground to an angle of  $60^\circ$ . A clearance angle of  $10^\circ$  is suitable for most work which means that the angle at which the chisel must be held must be  $30^\circ$  (half the chisel point angle) plus  $10^\circ$ , the clearance angle, which together equals  $40^\circ$ .

Soft metals, such as copper and aluminium, require a sharper chisel point than the harder ones. For example, an angle of  $30^\circ$  is suggested for aluminium while  $60^\circ$  is suitable for cast iron and mild steel.

Chisels are made of tool steel, usually of octagonal cross section, but there is no reason why model engineers should not make them, in the smaller sizes they require, from the more readily obtainable round carbon steel. They must, of course, be hardened and tempered in the usual way.

After prolonged use the head of the chisel becomes mushroomed shape with jagged edges projecting all around the striking face (see Fig. 6.4). When reaching this state the chisel is dangerous to use as small pieces may fly off when it is struck by a hammer, and an

**Fig. 6.4** Chisel with dangerous mushroom head.



injury to the face or eye may result. In my own area a 'scrappy' in a car breaker's yard lost the sight of an eye in this way. There is also the risk of the hand being injured by the sharp protruding edges. The jagged edges should be ground away on the emery wheel, so that the head is restored to the shape shown in Fig. 6.2.

When first attempting chipping work the beginner often misses the chisel and hits his hand. While in pain, and to avoid a repetition, he now watches the head of the chisel instead of the face of the work which is being chipped. This leads to further trouble as it is essential that the eye is directed at the actual formation of the chip.

The hammer shaft must not be gripped too tightly but held comfortably and the blows struck with a wrist action. A tight grip is not needed on the chisel; small chisels can be held between the thumb and two fingers but chisels of ordinary size have to be fully grasped. All hand operations are difficult to describe, so if possible watch an experienced man at work and copy his action. In any case 'have a go', perhaps at first on scraps of mild steel which you do not mind spoiling.

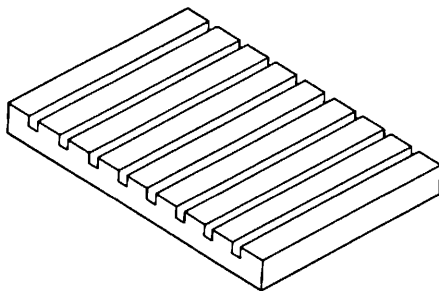
Exercise enough control of the chisel to keep it at the right angle, which has to be modified during progress across a face, according to how the cutting edge of the chisel is penetrating the work. Lower the angle if too much digging in has developed and raise it slightly if penetration is not deep enough.

The edges of metals, particularly the crystalline kind such as cast iron, are

liable to break away as the chisel reaches them. It is wise, therefore, to stop the cut before the edge is reached and then reverse the direction of the cut, that is to chisel inwards.

In the past, when a large area had to be reduced, grooves were cut across the face using a cross cut chisel, at a distance from one another slightly less than the width of the available flat chisel (see Fig. 6.5). The flat chisel was then used to bring the whole surface down to the level of the bottom of the grooves. With the machine tools now available I doubt if this is now ever done but the method is worth bearing in mind for use in an emergency when no other means of completing a job is at hand.

A flat chisel is a very useful tool for cutting sheet metal, particularly if the job is small enough to be held in the vice. The scribed line, indicating where the cut has to be made, is placed level with the vice jaws. The chisel is then



**Fig. 6.5** Grooves cut with cross-cut chisel ready for finishing with flat chisel.

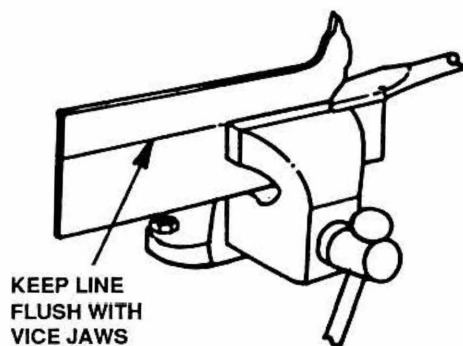
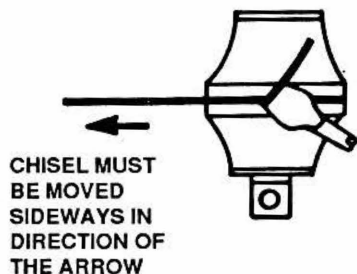


Fig. 6.6 Cutting sheet metal in the vice.

applied, using the vice as a guide, so that a shearing action occurs. With care a clean cut can be made. (See Fig. 6.6)

For anyone restoring old engines the chisel is a very valuable tool for such tasks as cutting off rivet heads and splitting seized nuts. I think it got its bad name from the practice of some bodgers using it to slacken a nut when a spanner of the correct size is unavailable. The condition of the nut after being mutilated in this way is a very sad sight. Properly used the chisel is a craftsman's tool not to be despised.

### PUNCHES

The CENTRE PUNCH is an essential tool in the fitter's toolkit. It is made of tool steel and is hardened and tempered in the same way as a chisel. Its point is ground to a fine conical shape. (See Fig 6.7) It is used for marking the centre point of holes to be drilled. As well as locating the position of the hole it also prevents the drill from wandering from its position during the starting process. It is also used to provide a point in

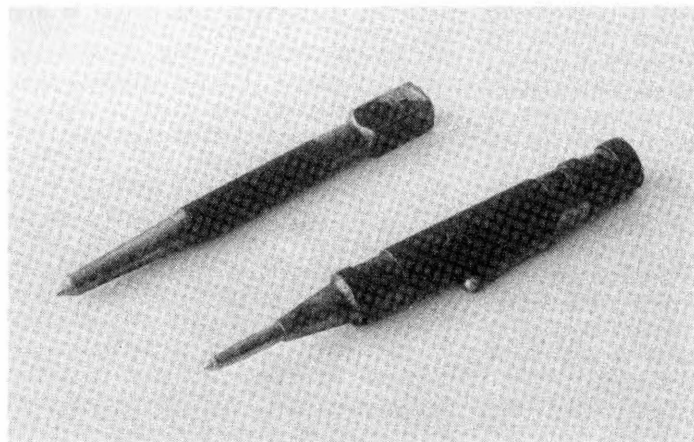
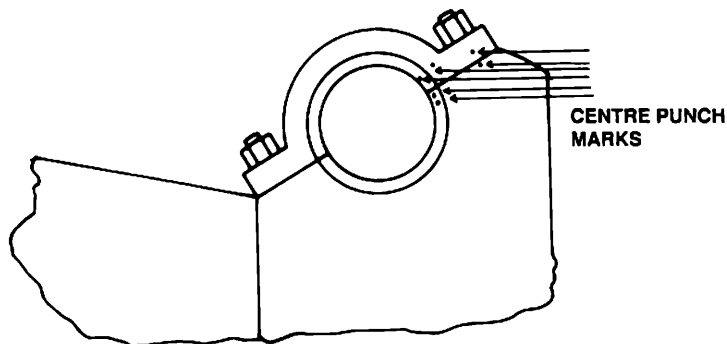


Fig. 6.7 Ordinary and automatic centre punches.

**Fig. 6.8** Main bearing marked with centre punch to ensure correct assembly.



which to place one leg of the dividers when a circle has to be scribed.

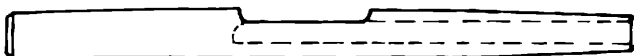
To ensure parts being dismantled are re-assembled in exactly the same position it is good practice to mark their position with centre punch marks. Fig. 6.8 shows how two bearing brasses are marked so that they are always assembled correctly.

In use the centre punch is held between the thumb and the first two fingers of the left hand in a vertical position with the point on the exact spot where the mark is to be made. It is then given a light blow with a hammer held in the right hand.

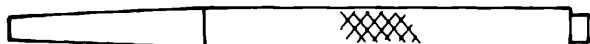
A DOT or PRICK PUNCH is similar to a

centre punch but is lighter with a finer point. It is used to mark the position of scribed lines so that the line may be restored if it becomes obliterated. This subject will be dealt with further in the chapter on marking out.

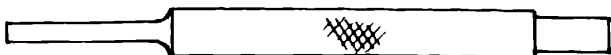
The AUTOMATIC CENTRE PUNCH has an internal spring mechanism. The point of a punch of this type is placed in position on the workpiece and pressure is applied to the top of the punch. This compresses the spring until the punch reaches a certain position where a catch is released. The energy from the spring is transmitted to the point of the punch and a light centre punch mark is made. Generally the punch has an adjustment



**Fig. 6.9** Pin punch.



**Fig. 6.10** Drift punch.



**Fig. 6.11** Hollow punch.



which regulates the force of the blow so that centre punch marks of varying depths can be made. See Fig. 6.7.

The PIN PUNCH (see Fig. 6.9) has a parallel round shank end instead of the tapered end on the centre punch. It is used for driving out pins, rivets or bolts from components. The shank at the end varies in size and when used a size a little smaller than the piece to be removed should be selected.

DRIFT PUNCHES are similar to pin punches except that instead of a parallel shank at the end, the end tapers. It is a general purpose tool with a variety of uses. It is particularly useful for imparting a blow in a confined space which cannot be reached directly by a hammer. Driving a ball race on to a shaft or into a housing is a typical example of the type of job for which the drift punch is used. (Fig. 6.10)

When cutting gaskets it is generally necessary to produce a number of holes in the gasket material to match those in the joint faces. HOLLOW PUNCHES in various sizes are used for this purpose. (see Fig. 6.11)

The punch has a hole in its end which extends some way into the body of the punch. A slot is machined in the side of the punch to meet the hole. The gasket material is placed on some relatively soft material, such as lead or a piece of hardwood, and the punch is placed in position where the hole is required and then struck with a hammer. A hole is made in the gasket material and the piece of material which has been removed travels up the hole in the punch, eventually being discharged through the slot. The gasket material must not be placed on steel, or similar hard metal, when gaskets are being made, as the punch will be blunted.

## CHAPTER 7

# SCRAPERS AND SCRAPING

Apparently flat surfaces are almost certain to have small irregularities, even though they have been carefully filed or machined. There are high spots and valleys and if the high spots are left between moving, mating surfaces they will rapidly wear down, leaving excessive clearance between the parts.

Scrapers are used for removing these high spots and in the hands of a skilled fitter small shavings of metal can be removed with the scraper as and where required. Internal cylindrical surfaces, such as engine main and big end bearings, can also be scraped so that they are a very good fit on their journals.

Scrapers are made in three shapes, flat for dealing with flat surfaces, half round for producing good mating surfaces between a shaft and its bearing, and a three-corner one. The last can be used in the same way as the half round one and it is also useful for de-burring holes.

Because of the high quality steel from

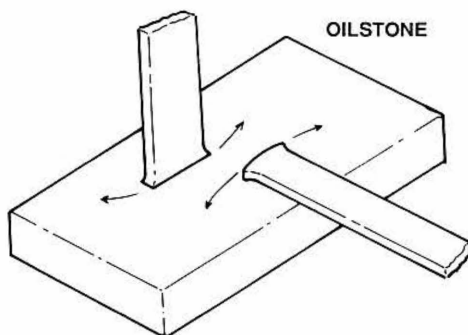
which files are made, old worn-out flat and half round files make very good scrapers. The file should be softened by heating in a fire to a red heat and then allowed to cool slowly in the ashes. It can then be forged and filed to the desired shape and finally re-hardened and tempered. This hardening and tempering process will be discussed later.

Since the cutting force on a scraper is comparatively light and without shock, its edge need only be given a slight degree of temper. This extra hardness is a distinct advantage because the cutting edges of scrapers tend to become blunt very quickly. An illustration of a flat scraper appears in Fig. 7.1.

If care is taken not to draw the temper of a flat file by letting it get too hot when shaping it on the emery wheel, it is possible to make a flat scraper without softening and re-hardening it. The teeth on the file are ground away and the end slightly radiused to prevent it digging in when in use.



**Fig. 7.1** Flat scraper.



**Fig. 7.2** Sharpening a flat scraper.

Once the cutting edge has been produced by grinding it must be sharpened on an oilstone. It is sharpened by holding it close to its cutting edge and adopting a rocking motion and by stoning the sides of the cutting edge until they are dead sharp, (see Fig. 7.2). The cutting edge must be kept very sharp so it is necessary to be constantly touching up the scraper on the oilstone as the work progresses.

The scraper only removes slight irregularities; it is not intended to

remove much metal. Assuming the surface is reasonably flat another perfectly flat surface is required with which to compare the surface being scraped. For this purpose a surface plate is needed. It is usually rectangular in shape and made of good quality, close-grained cast iron. It has several stiffening webs on its base to prevent any tendency for it to 'sag' (see Fig. 7.3). Surface plates are expensive and unlikely to be available in the model engineer's workshop. A sheet of thick plate glass is a very good substitute and an off-cut can probably be obtained from a builder's merchant with a glazier's department. I was fortunate in obtaining a piece with ground edges but if this is not available it is not a difficult job to provide a baseboard for the glass to sit on and to surround the glass with moulding not quite so deep as the glass is thick.

The surface plate, or glass, is thoroughly cleaned and then evenly smeared with engineer's blue. A tube of Prussian blue artist's oil paint will do if the proper 'blue' is not available. Alternatively fine red lead powder and thin oil, mixed to form a thin paste, can be



**Fig. 7.3** Surface plate.

used. The surface to be scraped is then placed on the surface plate and rubbed about slightly. All the high spots will now appear coated blue. These high spots are reduced in height by careful scraping as shown in Fig. 7.4.

The handle of the scraper is held in the right hand and the left hand presses on the blade. Short strokes are made, 12mm (1/2 in.) being about the correct length. The scraper is kept in contact with the surface of the work on the return stroke but no pressure is applied to it. Having gone over the work with strokes in one direction the next set of strokes should be made at right angles to the first.

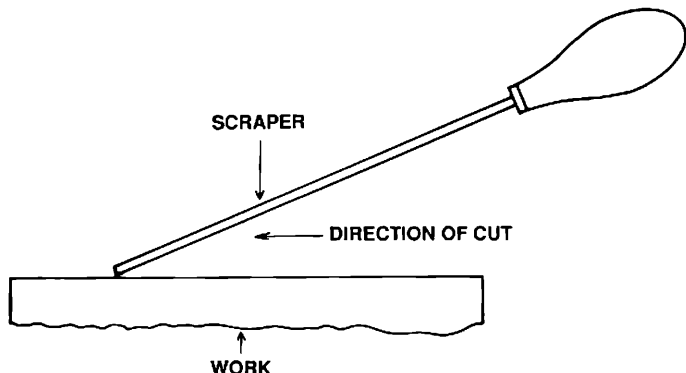
The work is cleaned off with a rag, the blue again evenly smeared on the surface of the surface plate and the work rubbed gently on the surface plate once more. The high spots now appearing are treated in the same way as before and the whole process repeated until the surface of the work is covered by small areas of contact fairly close to one another.

It is a mistake to apply the blue too thickly to the glass or the surface plate as a false reading may be obtained. Much patience and practice are necessary to produce accurate surfaces by

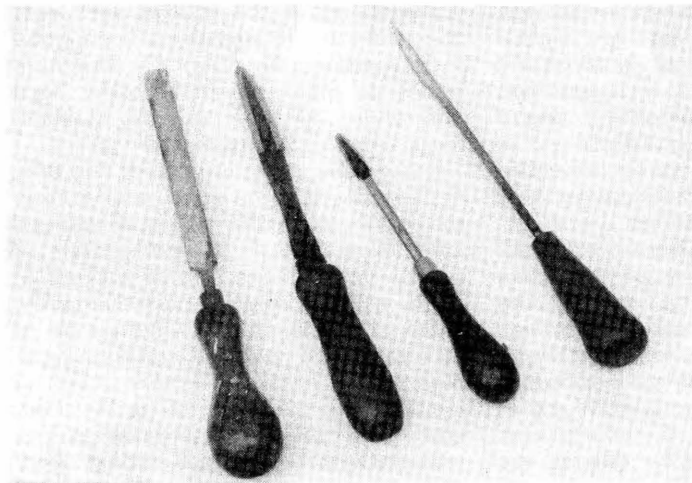
scraping but if the tool is kept very sharp and gentle pressure is used, good results should be obtained. The frost effect, so much admired on the beds and slides of high quality machine tools, can then be attempted.

If accuracy is not important and only appearance is to be considered a frosted effect can be obtained by cheating a little. Glue a 1/4 in. diameter circle of emery cloth on the end of a piece of 1/4 in. wooden dowel and place in the chuck of the bench drill. Oil the work to be treated and, with the drill running at high speed, bring the emery into light contact with the work. Move the work along and bring the emery into contact with the work again. Repeat the process until the whole of the area is covered with a series of shiny circles. The purist may hold up his hands in horror but the treatment does give the work a nice appearance and for some reason, which I cannot explain, makes ferrous metals corrosion resistant. Naturally discretion must be used with this practice and it is not recommended where accuracy is important.

The half round scraper can be made from a half round file. Scrapers are available commercially but there is much greater satisfaction when using



**Fig. 7.4** *Scraping a flat surface.*



**Fig. 7.5** Selection of scrapers. Note all are fitted with handles.

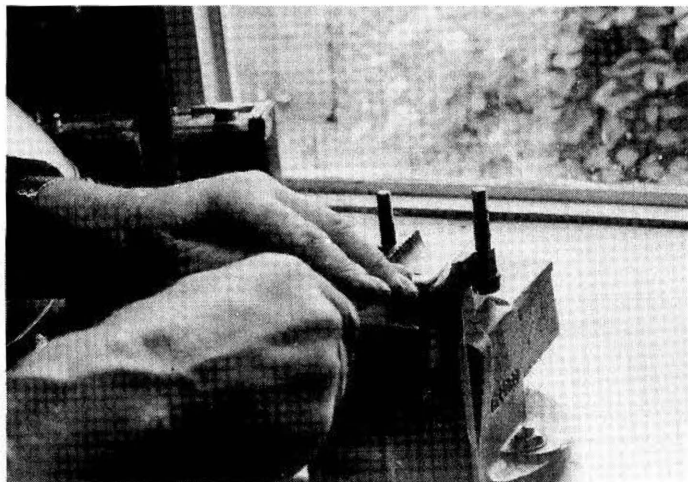
one you have made yourself than one you have bought from a shop. The file should be softened, as described above, and then forged and filed to shape. The centre of the working face is hollowed so that there is less metal in contact with the oilstone when the scraper is being sharpened. Get as fine a finish as possible, finishing off with fine emery paper. It must then be hardened and tempered and sharpened on the oilstone.

When I was an apprentice I made a half round scraper from the outer ring of a ball race. The ball race was dismantled and the outer ring softened by heating in the forge and allowing to cool slowly. It was then cut, straightened out and forged roughly to shape. The groove in which the balls used to run provided the correct hollow ground effect. It was filed to the correct shape and the firm's blacksmith offered to harden and temper it for me. He was a craftsman of the old school and got the degree of hardness just right. I have

used this tool for many years and it is still as good as new. I particularly remember during the war years, when I helped to keep an essential fleet of motor cars running, when new cars and spares for the old ones were unobtainable, using the scraper to scrape out the ridges at the top of the cylinder bores. The piston ring grooves were machined to fit new rings and these would have fouled the ridges as the pistons reached the top of their stroke if the ridges had not been removed.

The half round scraper is used for finishing the surface of bearings so that they are a good fit on their shaft. The shaft is smeared with a thin layer of 'blue', placed in position on the half bearing and rotated a few times and then taken out. The high spots on the bearing will be marked with blue and these marks are removed by the scraper. This process is repeated until the whole area of the half bearing shows contact with the shaft. When the bottom half bearing is finished the

**Fig. 7.6** *White metal  
big end bearing  
being scraped.*



other half is placed in position and treated in the same way, only in this case the two halves are bolted together. As well as getting a good surface fit the bearing must not be too tight or slack on its shaft. Shims (thin pieces of metal, usually brass) are fitted between the half bearings if the bearing is too tight and the half bearing carefully filed if it is too slack.

A selection of scrapers is shown in Fig. 7.5 and Fig. 7.6 shows a white metal

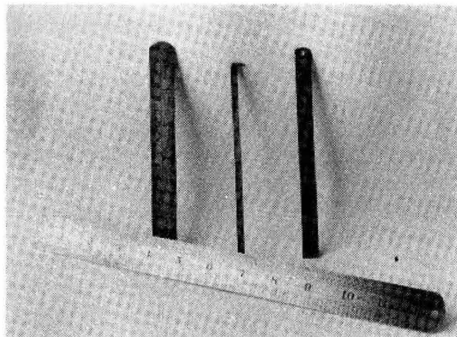
big end bearing being scraped. The right hand keeps the tool steady and exercises a certain amount of control and movement over the tool while the fingers of the left hand are placed on top of the scraper close to the work. The tool is drawn steadily across the work with slight pressure applied to enable the cutting edge to make the cut. Successive cuts should be made in opposite directions so that any high spots left from the previous cut are removed.

## CHAPTER 8

# MEASURING

Accurate measurement is the basis of good engineering practice. In the building trades craftsmen are content to use a wooden rule but the engineer always uses a precision engraved steel rule, and even this is used only for the least important measurements. Vernier calipers or micrometers are used when greater accuracy is required.

It could be argued that we should all be using the Metric system of measurement but many workshops are still committed to the Imperial system of feet and inches and, as far as possible, I shall be considering both systems.



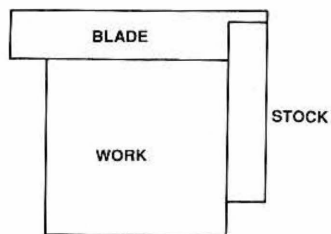
**Fig. 8.1** A selection of steel rules.

A 6 inch and a 12 inch steel rule with both metric and Imperial markings will cover most needs. One graduated in  $\frac{1}{8}$ ,  $\frac{1}{16}$ ,  $\frac{1}{32}$  and  $\frac{1}{64}$  in. on one side and millimetres and  $\frac{1}{2}$  millimetres on the other is ideal. A pocket steel tape, about 6 feet long, is useful for some classes of work.

The degree of accuracy to which work may be produced when only a rule is used depends on the quality of the rule and the skill of its user. It is extremely difficult to guarantee an accuracy much closer than within  $\frac{1}{64}$  in. or 0.3 mm.

It is important to own a good rule and to get used to using it. It must be looked after: the end particularly should be preserved from wear as it generally forms the basis for one end of the dimension. Rules should be oiled to prevent rusting when not in use. Fig. 8.1 shows a selection of rules.

The TRY SQUARE is the most common tool for testing squareness and Fig. 8.2 shows it in use. Try squares are precision instruments and must be treated with great care if they are to retain their initial accuracy. They must not be knocked or dropped and should be kept away from bench tools to avoid burrs occurring on the blade edge. They must be checked at regular intervals for



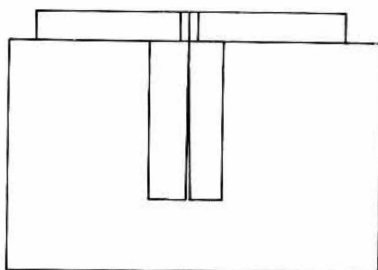
**Fig. 8.2** Try square in use.

squareness. This is done by the simple method illustrated in Fig. 8.3. Two lines are scribed in the manner shown and if the lines are not one over the other the square is faulty. This check is quite accurate as the error shown is double the error present in the square.

When two surfaces are at any angle other than  $90^\circ$ , the angle between them can only be measured with some form of PROTRACTOR. One with a graduated head is shown in Fig. 8.4. A more sophisticated type has a vernier attachment whereby very accurate readings may be obtained.

The BEVEL, shown in Fig. 8.5a, is a useful tool which is very easily made. In fact it forms a useful exercise in drilling and filing and a drawing for its construction is also shown in Fig. 8.5b. It cannot be set to a desired angle without some other aid and this limits its scope.

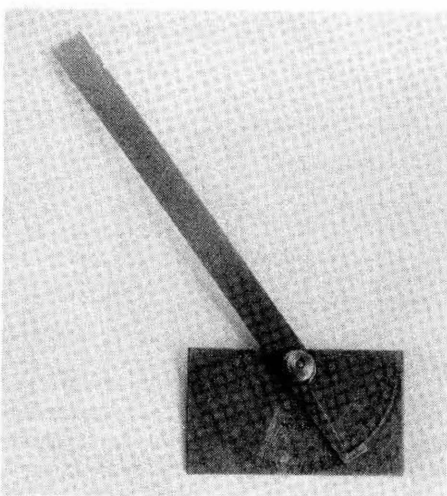
The COMBINATION SQUARE (Fig. 8.6) manufactured by Moore and Wright, a subsidiary of Neill Tools, is a versatile instrument. It consists of a hardened steel rule with Imperial graduations in 64ths of an inch and metric ones in  $\frac{1}{2}$  mm. The square head has a fixed angle of  $15^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$  and  $90^\circ$ . The centre head has a fixed angle of  $90^\circ$  for finding the centre of round or square bars. The protractor has a full  $360^\circ$  scale graduated  $0^\circ$  to  $180^\circ$  to  $0^\circ$ . It is satin



**Fig. 8.3** If scribed lines do not coincide when drawn with square in opposite positions the square is out of true.

chrome finished for easy reading. Fig. 8.7a shows some of its uses while Fig. 8.7b shows it being used to measure an acute angle.

CALIPERS AND DIVIDERS. Calipers are used for measuring distances between or over surfaces or for comparing distances or sizes with standards such as those on graduated rules. Their shape



**Fig. 8.4** Protractor with graduated head.



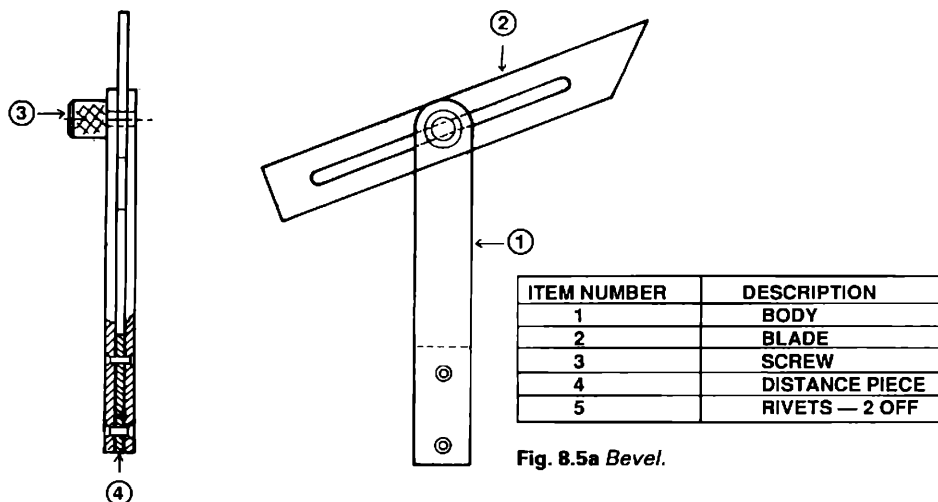


Fig. 8.5a Bevel.

varies according to whether they are for measuring internally or externally. Simple firm leg calipers are shown in Fig. 8.8 and spring operated calipers with a

screw adjustment appear in Fig. 8.9.

With care and skill very accurate results can be obtained with calipers, in fact the old millwrights used them

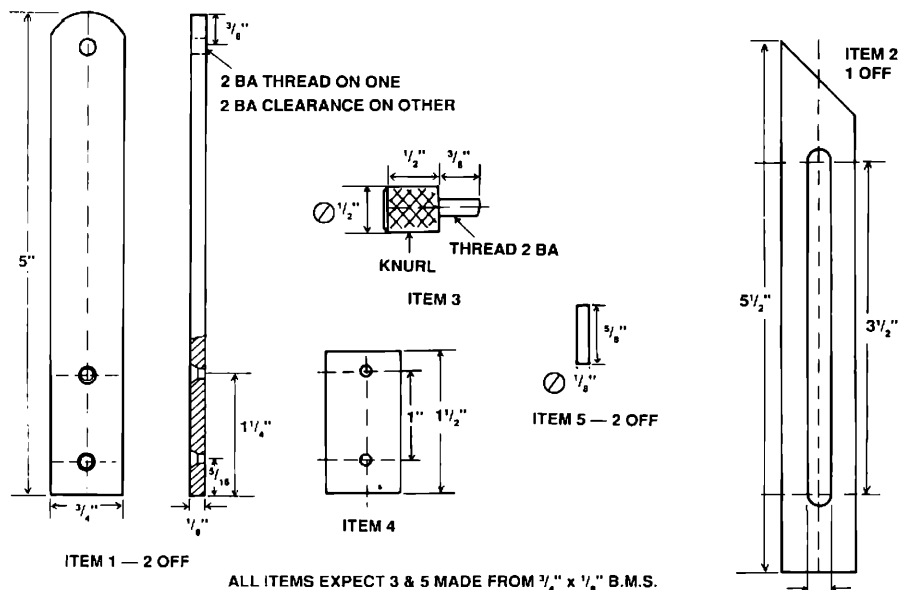
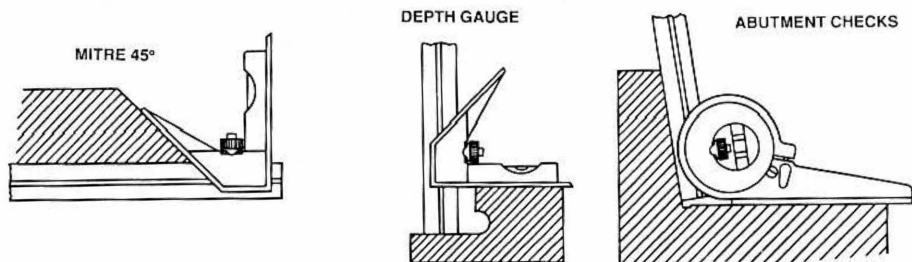
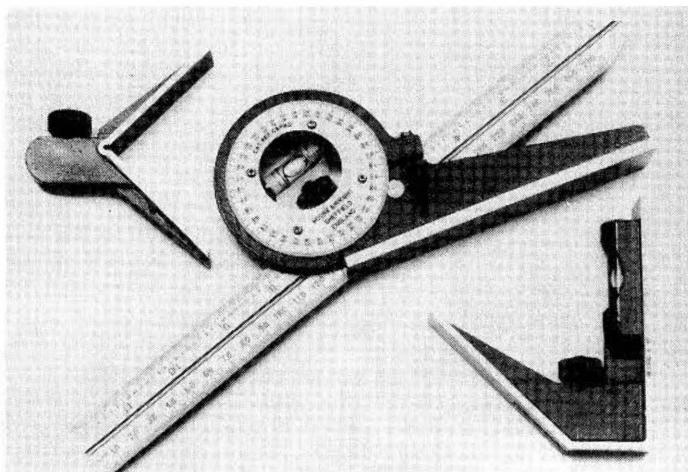


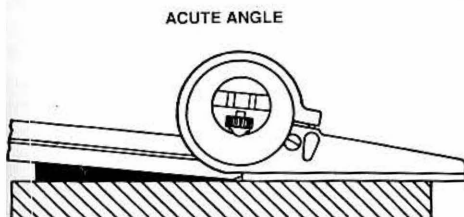
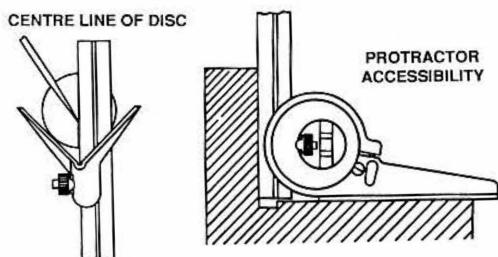
Fig. 8.5b Bevel details.

**Fig. 8.6** Combination square.

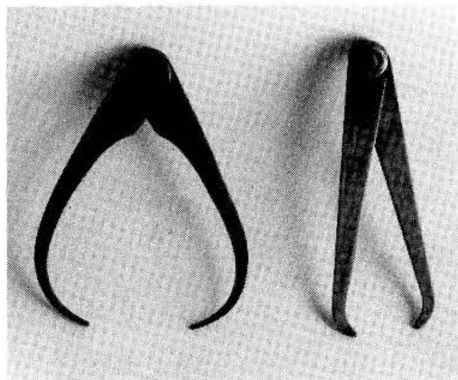


**Fig. 8.7a** Various uses of the combination square.

**Fig. 8.7b** (belcw). Combination square used to measure an acute angle.



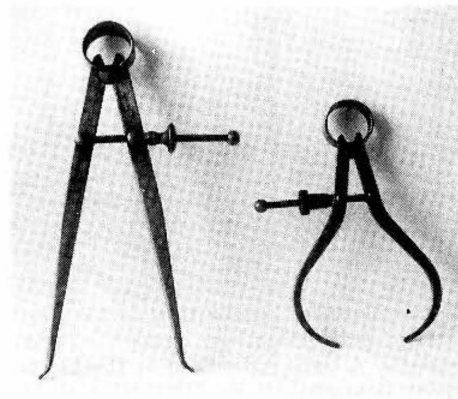
exclusively for measuring large diameters and obtained very accurate results. A very light hold at the caliper joint is essential. The action of sliding over the object to be measured must be



**Fig. 8.8** Firm leg calipers.

a very delicate one so that the sense of touch notes the faintest difference in pressure at the caliper points. Failure to operate in this gentle manner will cause the points of the caliper to be forced over the work, springing the legs apart and giving a false reading.

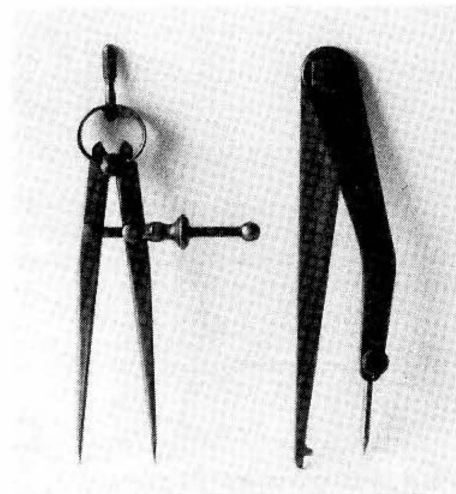
It is more difficult to measure bores accurately because of the difficulty in setting the points of the calipers across the absolute centre of the bore. If care is



**Fig. 8.9** Calipers with screw adjustment.

taken in pushing the caliper into the bore and wriggling it up and down and sideways the highest point can be felt.

Calipers can be set from a sample of work, from a rule or from a micrometer. Probably the most accurate setting can be obtained from a sample piece of work. In setting from a rule it is necessary to be very careful, first, not to use an old rule which has become worn at the end and second, to set the caliper



**Fig. 8.10** A pair of dividers and a hermaphrodite caliper, better known as 'odd legs' or 'Jennies'.

point so as to exactly split the line of graduation on the rule.

Quite accurate results can be obtained by setting calipers using a micrometer. This is often useful when it is necessary to measure the inside diameter of a bush or cylinder. The inside calipers are used to measure the bore and then the calipers are measured with the micrometer. If the same care is taken as was recom-

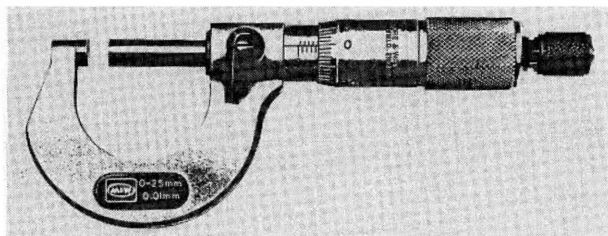


Fig. 8.11 Moore & Wright metric micrometer.

mended in the previous paragraphs very accurate results can be obtained.

**DIVIDERS**, (Fig. 8.10) are used for scribing circles and marking off lengths. **HERMAPHRODITE CALIPERS** are half calipers and half dividers. (Fig. 8.10). More generally known as **ODD LEGS** or **JENNIES**, their use and the use of dividers will be dealt with in the chapter on Marking Out.

**MICROMETERS**. Where very accurate measurements are required it is necessary to use a micrometer with which it is possible to make readings to 0.001 in. or 0.01 mm. An illustration of a Moore and Wright metric micrometer appears in Fig. 8.11. The inch type is of similar construction but the graduations, quite obviously, are different.

The micrometer consists of a semi-circular frame having a cylindrical

## IMPERIAL

### To read in one thousandths of an inch (0.001").

First note the whole number of major divisions (tenths of an inch or 0.1" shown on the sleeve)

Then note the number of minor divisions after the whole number (each minor division is equal to a quarter of a major division, i.e. Twenty five thousandths of an inch or 0.025")

Finally, read the line on the thimble coinciding with the datum line. This gives thousandths of an inch.

$$\text{Two} \times 0.1 = 0.2"$$

$$\text{Three} \times 0.025 = 0.075"$$

$$\text{Eleven} \times 0.001 = 0.011"$$

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$$\text{TOTAL} = 0.286"$$


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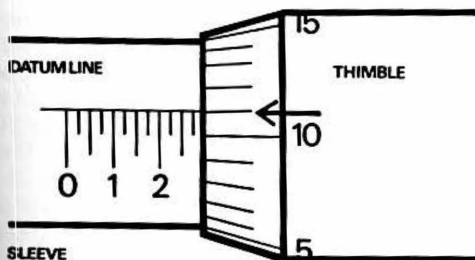


Fig. 8.12 Reading the inch micrometer.

## METRIC

### Reading in hundredths of a millimetre (0.01 mm).

- 1 First note the whole number of mm divisions on the sleeve (Major divisions – below datum line)
- 2 Then observe whether there is a half mm visible (minor divisions above datum line)
- 3 Finally read the line on the thimble coinciding with the datum line. This gives hundredths of a mm.

$$\text{Ten} \times 1.0 = 10.0 \text{ mm}$$

$$\text{One} \times 0.5 = 0.5 \text{ mm}$$

$$\text{Thirty-three} \times 0.01 = 0.33 \text{ mm}$$

$$\text{TOTAL} = 10.83 \text{ mm}$$

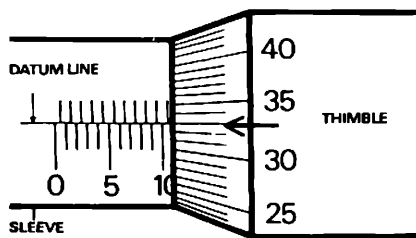


Fig. 8.13 Reading the metric micrometer.

extension, the sleeve, at its right end and a hardened anvil at the other end. The bore of the sleeve is threaded and a spindle screws into the bore. The spindle carries a graduated thimble which turns at one with it.

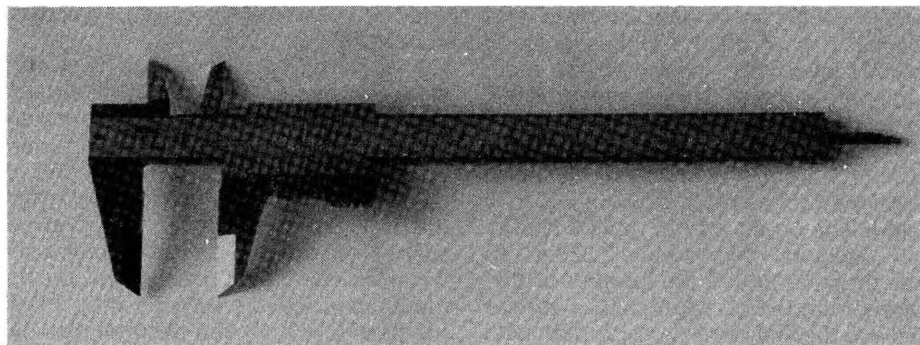
**Reading the 'Inch' Micrometer** The inch reading micrometer screw has 40 threads per inch so that in one complete revolution it moves  $\frac{1}{40}$  in. (0.025 in.) In  $\frac{1}{25}$ th of a turn it will move  $\frac{1}{25}$  of  $\frac{1}{40}$  in. which is 0.001 in. The sleeve has marked on it major divisions representing tenths of an inch – that is 0.100 in. Each major division is sub-divided into four minor divisions representing 0.025 in. each.

The thimble is divided into twenty-five parts round its bevelled circumference and as one full turn is equal to one minor division on the sleeve (0.025 in.) then one division on the thimble will be 0.001 in. Fig. 8.12 shows how 0.286 in. reads on a micrometer.

**Reading the Metric Micrometer.** The screw on metric micrometers has a pitch of  $\frac{1}{2}$  mm so two revolutions of the thimble will move the spindle through 1 mm. On the sleeve the datum line is graduated with two sets of lines, the one below the datum reading in millimetres and the set above reading in half millimetres. The thimble scale is marked in fifty equal divisions, figured in fives, so that each small division on the thimble represents  $\frac{1}{50}$  of  $\frac{1}{2}$  mm which equals  $\frac{1}{100}$  mm, which is 0.01 mm.

To read the micrometer first note the whole number of millimetre divisions on the sleeve (major divisions), then observe if there is a half millimetre visible (minor divisions) and lastly read the thimble for hundredths (thimble divisions) i.e. the line on the thimble coinciding with the datum line. This procedure is plainly set out in Fig. 8.13.

An inch and a two inch micrometer or their metric equivalents will cover most needs, although larger sizes are avail-



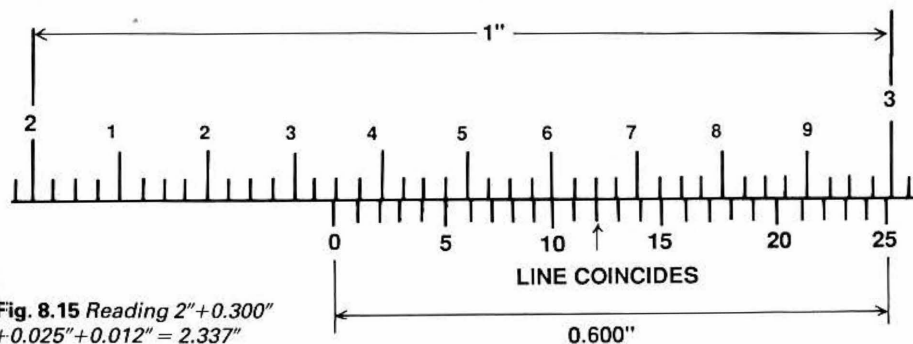
**Fig. 8.14 Vernier caliper.**

able. The larger ones usually have a frame into which various length anvils can be inserted to cater for the different lengths to be measured. The actual measuring mechanism is the same as it is on the smaller sizes.

THE VERNIER CALIPER, Fig. 8.14, is used for measuring work where the micrometer cannot be used, or for work outside a micrometer's capacity. Most verniers can measure inside, outside and depth dimensions. It consists of a beam which has a fixed jaw at one end and also a sliding jaw. The beam is graduated with both Imperial and metric scales.

**Reading the Inch Vernier.** The main scale on the vernier is graduated and numbered in inches with each inch graduated and numbered in tenths (0.1 in.). Each tenth is divided into four giving 0.1 in. divided by 4 = 0.025 in. On the sliding jaw 0.6 in. is divided into 25 parts. Each of these has a length of 0.6 in. divided by 25 = 0.024 in. The differences in length between a small division on the fixed scale and the sliding scale is  $0.025 - 0.024 = 0.001$  in.

If the zero on the main scale and the zero on the sliding scale are level and then the sliding scale is moved until the first small marks on both scales are level the movement will have been



**Fig. 8.15 Reading  $2'' + 0.300'' + 0.025'' = 2.337''$**

0.001 in. If the sliding jaw is moved until the 16th mark on the sliding scale is exactly level with a mark on the main scale, the sliding scale has moved 0.016 in. and so on.

To read a measurement note the position of the zero line on the vernier scale in relation to the main scale. In Fig. 8.15 this is shown as 2.00 in. plus 0.300 in. plus 0.025 in. which equals 2.325 in. To this must be added the number of divisions from the zero line on the vernier scale to the line which is coincident with a line on the main scale, in this case 12 divisions which equals 0.012 in. the total reading is, therefore:—

Main scale	2.325 in.
Vernier scale	0.012 in.
	<hr/>
	2.337 in.

**Reading the Metric Vernier** The main scale on the metric vernier is graduated in millimetres and numbered every ten divisions. The vernier scale is divided into fifty divisions over a distance of 49 mm, each division equalling  $\frac{49}{50}$ th of a millimetre (0.98 mm). The difference between a division on the main scale

and the vernier scale is  $\frac{1}{50}$ th millimetre (0.02 mm).

The metric vernier is read in a very similar way to the inch one already described. To read the measurement note the main scale measurement immediately preceding the zero line on the vernier scale. To this must be added the decimal reading on the vernier scale. Note the line on the vernier scale which is coincident with a line on the main scale. Let us assume that this is the third line after the decimal number 0.7. Then we shall have to add 0.7 plus three divisions of 0.02 mm = 0.76 mm. This figure is then added to the main scale reading.

It cannot be emphasised too strongly that measuring and testing tools are precision instruments which must be treated with great care. They should not be left lying on the bench where they can become damaged by coming into contact with other tools or workpieces. If a protective case or box is provided they should be returned there after being carefully cleaned. If the tool is likely to be out of use for some time a thin coat of a non-corrosive oil should be applied to the measuring faces and bright spots.

## CHAPTER 9

# MARKING OUT

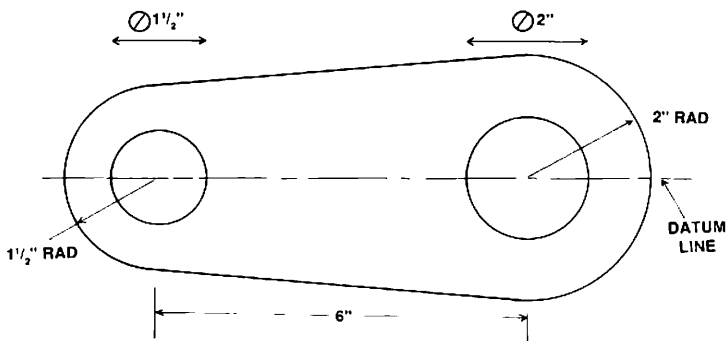
Except for very simple operations, such as filing the end of bar material square, it is necessary, before starting work, to scribe lines indicating the profile or outline of the finished article and the position of any holes. This process is known as 'MARKING OUT'.

A special cellulose lacquer, usually blue in colour, is available for applying to any bright surface, so that scribed lines show up clearly. When applied *thinly* it dries very quickly. It must be kept in an airtight container to prevent evaporation; sometimes it is supplied in a properly designed dispenser bottle complete with brush. It can also be obtained in an aerosol container so that it can be sprayed on the work but this is

rather wasteful as much of the spray misses the target.

Rough castings and forgings are usually painted with a light distemper or emulsion paint thinned down with water. Recently someone recommended the typewriter correcting fluid 'Tipp-Ex'. I know this dries very quickly but I have not tried it out for marking out purposes. I should think it is rather an expensive method compared with emulsion paint.

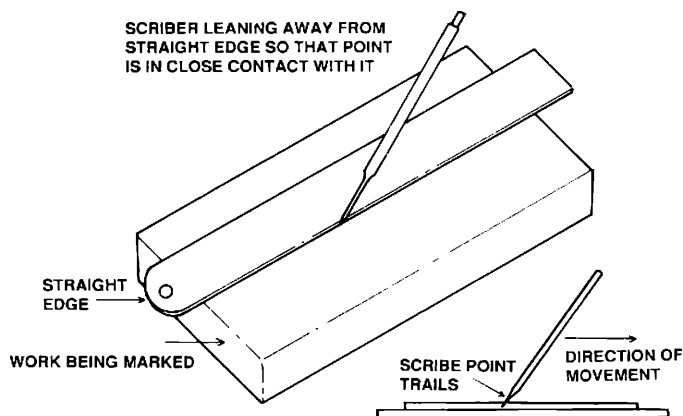
Although some of the tools used for marking out are used exclusively for this purpose, others are in general use in the workshop. The SURFACE PLATE, for example, was described in Chapter 7 when scraping a flat surface was



**Fig. 9.1**  
*Marking-out  
exercise on  
link.*



**Fig. 9.2 Use of scriber.**



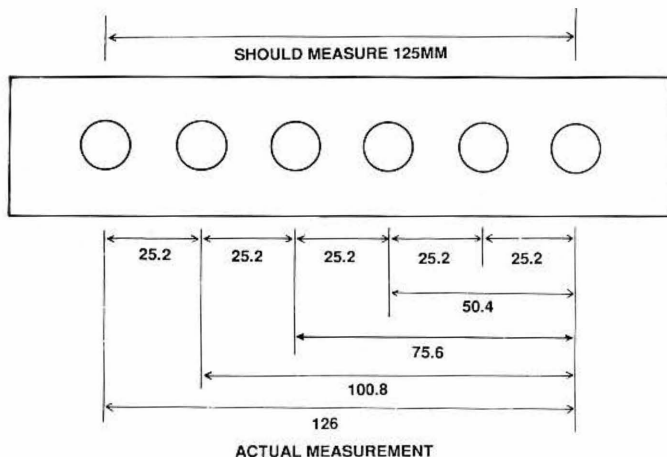
described. Dividers, the odd leg calipers and the try square were all dealt with in Chapter 8 on 'Measuring'.

Before marking out, a datum line or surface must be established. A simple example of the use of a datum line is shown in Fig. 9.1. The link illustrated is to be made from  $\frac{1}{2}$  in. steel plate. The centre line is the datum line in this instance and is scribed using a SCRIBER. The scriber must have a fine sharp point kept in good condition on an oilstone; a grinding wheel should not be used for this purpose. Gramophone needles as used on the old 78 r.p.m. machines make excellent scribers, when held in a pin vice. Unfortunately they are now difficult to obtain, but ready-made scribers are not very expensive. The correct method of using a scriber is shown in Fig. 9.2.

Getting back to marking out the link, after the centre line has been scribed the centres of the two holes are marked out. Having made a light centre-punch mark locating the centre of one of the holes the dividers are set to 6 inches and the position of the second hole is found by placing one leg of the dividers

in the centre-punch mark and scribing an arc on the centre line. A centre-punch mark is then made where this arc meets the datum line. The outlines of the two holes are now scribed in, with the dividers, one with a radius of 1 inch and the other with a radius of  $\frac{3}{4}$  inch. The 2 inch radius at the end of the link with the larger hole is now scribed in followed by the  $1\frac{1}{2}$  inch radius at the other end. These two radii are then joined with tangential lines using a rule to guide the scriber. The scribed lines can be made more permanent with light centre-punch marks. The depth of the two centre-punch marks in the centres of the holes should now be increased to allow the drill to make an accurate start.

To avoid error each feature of the component should be marked out from the datum line or surface and not from one another. Take, for example, the series of holes shown in Fig. 9.3, which are required to be 25 mm apart. Let us suppose that the dividers are set, in error, at 25.2 mm. Then if each hole is marked off from the one next to it the error in the position of the last hole will be 1 mm, i.e. it will be 126 mm away



**Fig. 9.3**  
Cumulative  
error  
caused by  
not  
measuring  
from  
datum line.

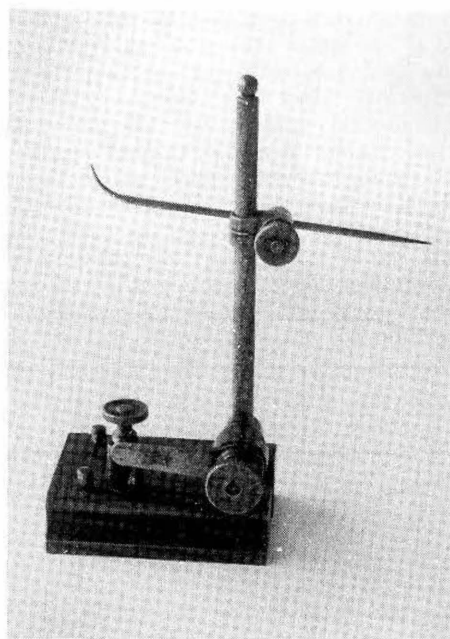
from the first hole instead of the correct dimension of 125 mm.

The link we marked out was only 'flat' work and when solid objects have to be dealt with additional equipment is required. In the first place a flat surface on which the work can stand must be provided and the SURFACE PLATE is used for this purpose. As stated earlier, a piece of plate glass makes an excellent substitute if a surface plate is unavailable.

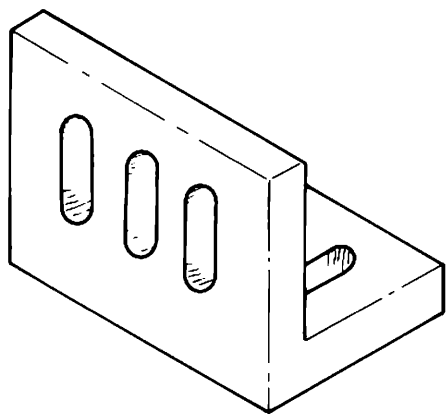
For scribing lines at a given height above the base, the SURFACE GAUGE, Fig. 9.4, is used. The spindle can be adjusted to any height and then sensitively adjusted to position by the knurled nut. The head carrying the scriber is so made that when the clamp nut is loosened the scriber can be freely moved to any position on the spindle.

The height of a scriber point on a surface gauge is set against a rule held truly vertical to the surface plate by being pressed against an angle plate. Alternatively a combination square can be used, the rule being held vertical with the square head resting on the surface plate.

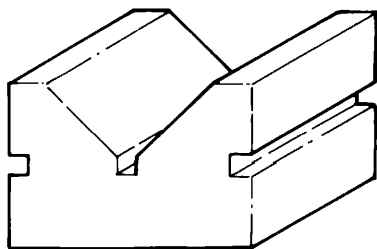
The ANGLE PLATE, Fig. 9.5, is used for supporting a surface at right angles to the surface of the surface plate. It is



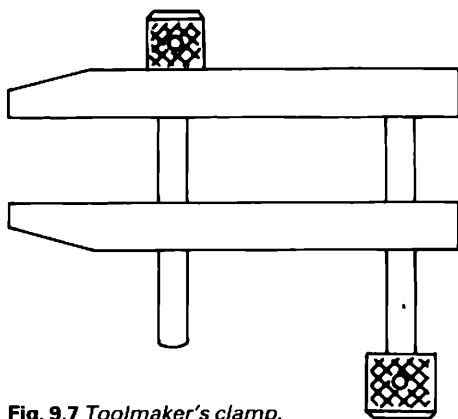
**Fig. 9.4** Surface gauge.



**Fig. 9.5** Angle plate.



**Fig. 9.6** V-block.



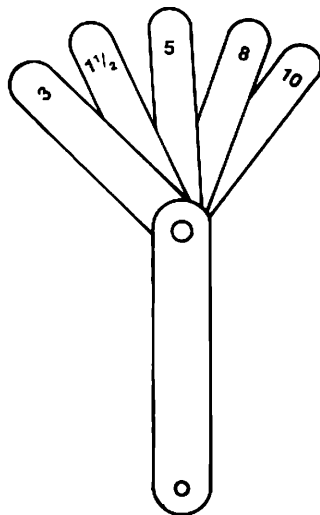
**Fig. 9.7** Toolmaker's clamp.

provided with holes or slots to accommodate bolts needed to secure articles to it.

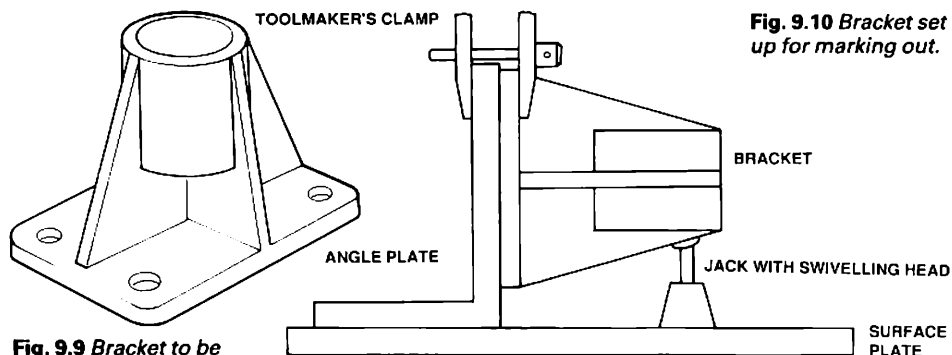
The VEE BLOCK, Fig. 9.6, is used for supporting shafts and bushes. They usually come in pairs and a clamp is generally provided for holding work in the 'V'.

TOOLMAKERS CLAMPS, Fig. 9.7, are essential items in a fitter's tool kit. They are used for clamping work to an angle plate when marking out and for many other purposes. They are very useful, for example, for clamping two pieces of work together when holes have to be drilled in alignment in both pieces.

FEELER GAUGES, Fig. 9.8, consist of a series of thin blades of different thicknesses, housed in a container in much the same way as the blade of a pen-knife. There are about ten blades in each tool and each blade has its thickness marked upon it. The blades on an



**Fig. 9.8** Feeler gauges.

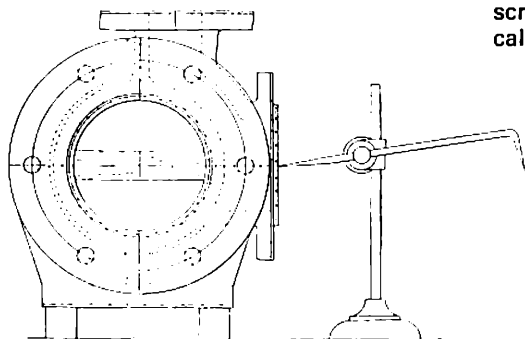


**Fig. 9.9** Bracket to be marked out.

Imperial set are invariably marked in 'thous', their thickness varying from 0.0015 in. to 0.025 in. The blades on a metric set are marked in 100ths of a millimetre and range from 0.05 mm to 0.8 mm. They are used to gauge small distances between adjacent surfaces.

When marking out on a surface plate steps must be taken to ensure that the component to be marked out sits firmly on the surface plate without any tendency to rock. Sometimes it is necessary to file or machine the surface lightly to achieve this. In other cases packing pieces or small jacks are used to keep the casting resting firmly in the required position.

A set-up for marking out the bracket shown in Fig. 9.9 appears in Fig. 9.10. The base of the casting is clamped to an angle plate with toolmaker's clamps while a small jack with a swivel head supports the inclined surface. The small holes will be plugged with discs of wood to allow centres and lines to be marked while a bar of wood or steel will span the large cored hole. Fig. 9.11, where a cylinder is being marked out, shows a strip fitted across the bore of the cylinder to provide a surface for the centre-punch mark necessary for scribing the circle showing the outline of the cylinder bore. Horizontal lines are scribed with the surface gauge and vertical ones by using a set square and scriber or, in some cases, the odd leg calipers.



**Fig. 9.11** Cylinder being marked out. Strip across bore for dividers to mark out circle showing position of bore.

## CHAPTER 10

# DRILLS AND REAMERS

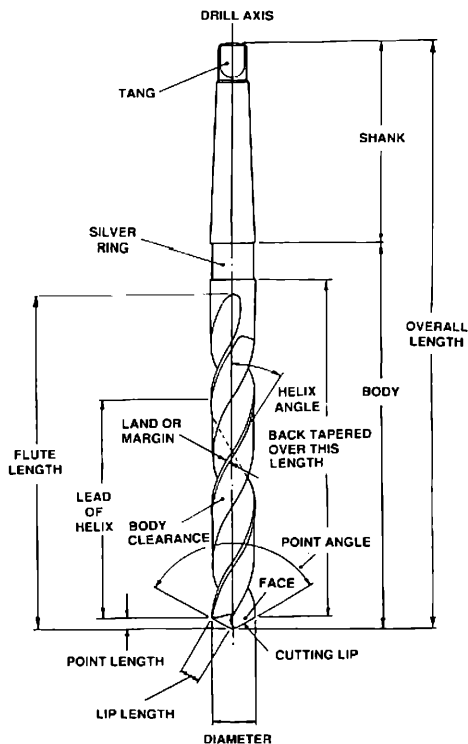
Much of an engineer's time is spent drilling holes and to obtain the best results, that is to produce a hole of the correct size, in exactly the right place, with a good finish, requires a certain amount of expertise.

Years ago flat drills, of the type shown in Fig. 10.1, were used but, although they are still handy for special jobs and can be made in the workshop, they have serious drawbacks. The advent of the twist drill, of the type used in industry and by model engineers, was an important advance.

Fig. 10.2 shows a Dormer drill and gives twist drill nomenclature. The drill illustrated is provided with a Morse



**Fig. 10.1** Flat drill

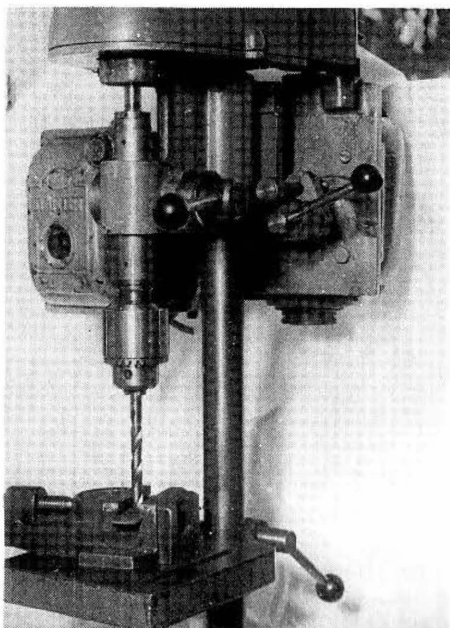


**Fig. 10.2** Dormer drill with Morse taper shank.

taper but, of course, drills with straight shanks which can be held in a drill chuck are also made.

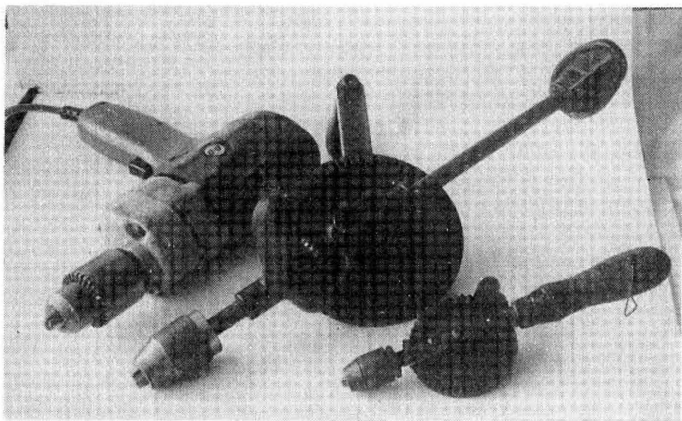
Most workshop drilling will be done in a pillar or bench drilling machine. Fig. 10.3 shows a machine of the latter type in use. When the drilling machine cannot accommodate the work or the work cannot be brought to the machine, a portable drill, either hand, breast or electric, is used (Fig. 10.4). With these types difficulty may be experienced in keeping the drill square with the work and a small square is useful in checking that the drill is at right angles to the work. It is an advantage if this checking can be done by a helper as it is difficult to operate the drill and see that it is square with the work at the same time.

Standard twist drills are ground with an included angle of  $118^\circ$ , established as the most suitable for general purpose work. If the correct initial clearance is produced and increased gradually towards the centre to produce a chisel edge angle of approximately  $130^\circ$  the correct clearance will be achieved along the whole of the cutting lip. The two cutting lip lengths should

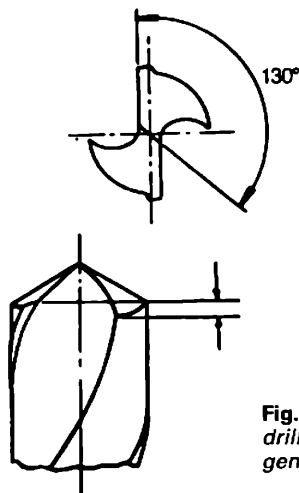
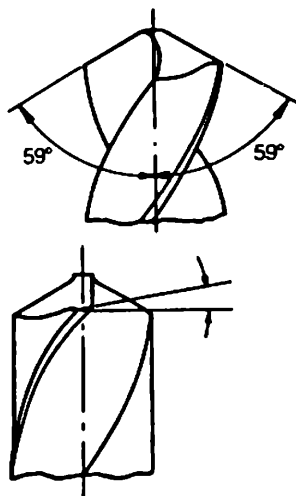


**Fig. 10.3** Bench pillar drill.

be equal and at a similar angle to the drill axis to provide correct balance and concentricity. (See Fig. 10.5).



**Fig. 10.4** Hand, breast and electric drills.



**Fig. 10.5** *Correct drill angles for general work.*

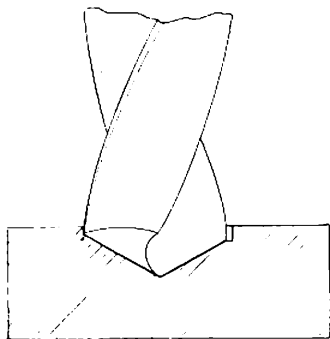
It is recommended that the angle of drills be altered for drilling certain metals and for some special jobs but it is not generally necessary unless a great deal of drilling of these metals is done. The standard  $118^\circ$  angle drill will cater for most jobs if care is taken.

To sharpen a drill by hand and to produce the correct angles is extremely difficult but at the same time accuracy is essential. For example, if the lips of the

drill are of different lengths an oversize hole will be produced (see Fig. 10.6). There is no doubt that a well-designed drill grinding device is a great asset to any workshop. I have found the Newmartek drill sharpener very satisfactory. It will be seen from Fig. 10.7 that the power for the grindstone is provided by an electric drill. Needless to say I have no connection with the makers of this tool.

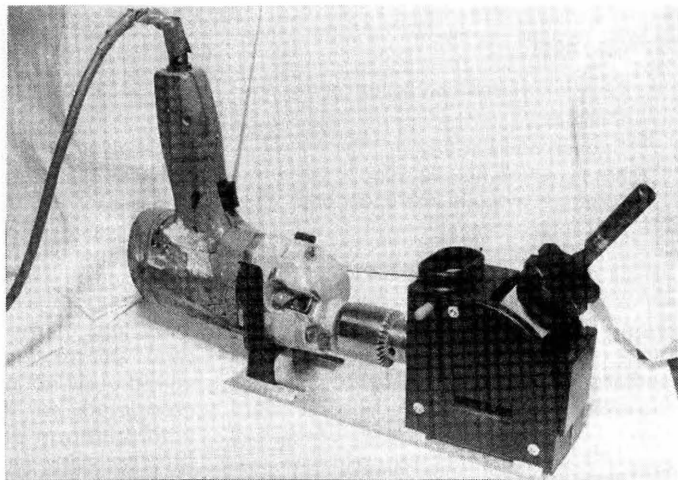
The Dormer Drill Information Handbook gives the following general hints on drilling. (I always believe in going to the experts for the best advice):

- (1) Keep drills sharp. Frequent re-sharpening is good economy. It is wasteful to delay resharpener a drill.
- (2) When a drill is being point ground ensure that all wear is removed and that the correct point angles are produced.
- (3) The chuck in which a straight shank drill is held must be of good quality. If the drill slips in the chuck and the



**Fig. 10.6** *Drill lips of different lengths produce oversize holes.*

**Fig. 10.7** Newmartek drill grinding jig.



feed is automatic, breakage of the drill is inevitable.

- (4) When driving taper shank drills into sockets use a soft face hammer. Make certain that there is a good fit between the taper shank of the drill and the sleeve or socket, otherwise the tang may break.
- (5) The work must be held rigid and the machine spindle must have no play.
- (6) Use recommended lubricants. Take care to ensure that the lubricant reaches the point of the drill.
- (7) Do not allow the drill flutes to become choked with swarf.
- (8) Use multi-fluted drills for opening out existing or cored holes. Two-fluted drills are not designed for this purpose.

For anyone just setting up a workshop, and for industry, drills in metric sizes are the best buy. However, fractional drills, that is those in sizes such as  $\frac{1}{16}$  in.;  $\frac{1}{8}$  in.;  $\frac{1}{4}$  in. and  $\frac{1}{2}$  in., are very useful and the older engineer still uses them. The third category, number drills,

is now rarely used in industry and sometimes can be difficult to obtain, but these drills are extremely useful to the model engineer. They range from the smallest, No 80 with a diameter of 0.0135 in., to No 1 – diameter 0.228 in. They are particularly useful for tapping and clearance drills for B.A. threads. Letter drills follow on with 'A' 0.234 in. up to 'Z' with a diameter of 0.413 in.

Drills are made from high speed or carbon steel. The latter are cheaper but not recommended; it is worth while paying the little extra for the high speed steel type.

The drilling of most metals is greatly improved by the use of a cutting lubricant, though cast iron should always be machined dry. Brass and bronze can generally be machined dry although some authorities recommend a lubricant. Steel should always be drilled with a lubricant.

By using a lubricant the drill and the work are cooled and a higher speed can be used; the cutting fluid helps in lubri-



TABLE 1

MATERIAL	CUTTING LUBRICANT
Aluminium and magnesium alloys	Soluble oil or neat cutting oil
Cast iron	Dry
Copper, brass or bronze	Soluble oil or dry
Mild steel, alloy steel, steel forgings, wrought iron and monel metal	Soluble oil or sulphurised oil
Stainless steel	Tallow, turpentine, soluble oil or sulphurised oil

cating the severe rubbing action taking place between the drill lip and the work and the lubricant helps to wash away the chips and keeps the cutting point clear. Cutting lubricants may consist of pure oil, a mixture of two or more oils or a mixture of oil and water. Sometimes sulphur is added to give the property of 'wetting' the metal with a highly adhesive oil film. The most common type of lubricant is a soluble oil which when mixed with water forms a white milky solution known as 'suds' or 'slurry'. The supplier's instructions should be followed as regards the proportion of oil and water required. Table 1 gives some guidance on the lubricants to be used when drilling various metals.

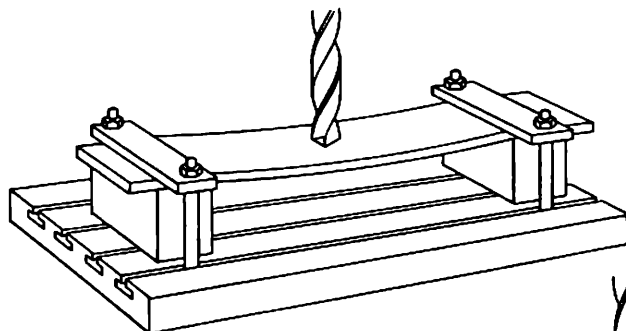
Drilling at the right speed is important. In production engineering the speed at which drills are run is carefully calculated so that maximum output with optimum drill life is obtained. The fitter working in the general engineering workshop or the model engineer will not go to this length but better results can be obtained if a speed approximating to the correct one is used. Handbooks published by the drill manufacturers and books on workshop practice give the peripheral speed for drills operating on various materials and from these the R.P.M. can be worked out using the following formula:

$$\text{Rev/min} = \frac{\text{Feet/min} \times 12}{3.142 \times D}$$

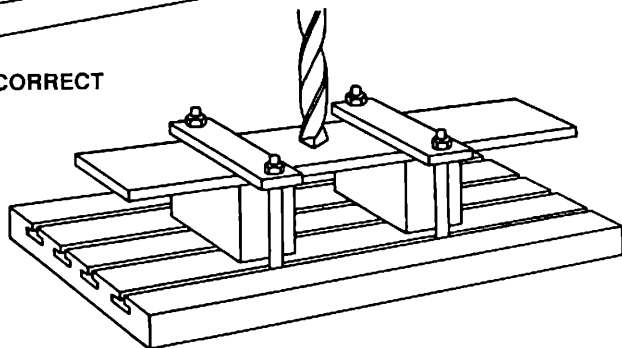
TABLE 2

MATERIAL TO BE DRILLED	SPEED feet/min	SPEED Metres/min
Aluminium and aluminium alloys	100 to 200	30 to 61
Brass	100 to 150	30 to 46
Brass, leaded	100 to 200	30 to 61
Bronze, ordinary	100 to 200	30 to 61
Bronze, high tensile	70 to 100	21 to 30
Grey cast iron	80 to 100	24 to 30
Copper	100 to 150	30 to 46
Monel metal	20 to 50	6 to 15
Free cutting mild steel	80 to 100	24 to 30
High tensile steel	50 to 70	15 to 21

**Fig. 10.8a** Supports too far apart, allowing job to sag.



**INCORRECT**



**CORRECT**

**Fig. 10.8b** Job properly secured by clamps.

where feet/min = peripheral speed of the drill in feet per minute and  $D$  = the diameter of the drill in inches.

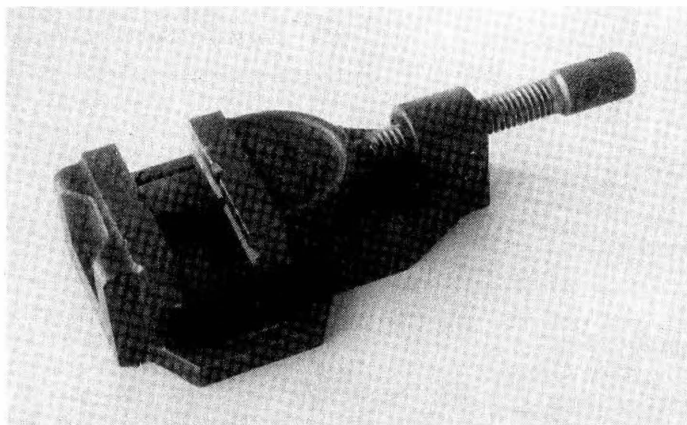
Table 2 gives the recommended speed for various materials.

The work being drilled must be securely fastened to the drilling machine table. This is particularly important when thin sheet metal is being drilled. When the drill is about to break through the metal it tends to jam in the hole, causing the metal being drilled to spin around. If the metal is held in the hand a nasty injury can be caused. Sheet brass is very prone to this nasty trick. A machine vice or clamps should be used to secure the work. Fig. 10.8b shows a piece of metal properly secured by clamps while Fig. 10.8a shows the supports too far apart, allowing the work to flex and spring.

The small MACHINE VICE shown at Fig. 10.9 has jaws  $2\frac{1}{4}$  in. wide and the sliding and the fixed jaws both have Vs in a horizontal and vertical position to facilitate the holding of round material. The sliding jaw is constructed so that it can swivel, allowing tapered or irregular shaped work to be held. The side of the jaw against which the screw abuts is semi-circular in shape so that it can be tightened at any angle.

Heavier vices of greater capacity and suitable for use on large drilling machines are obtainable.

V-blocks, described in Chapter 9, are used for holding work on the drilling machine table, especially for cross-drilling shafts. Very often it is necessary to drill a hole across the exact centre of a piece of round material and this is not easy. A small error results in the hole



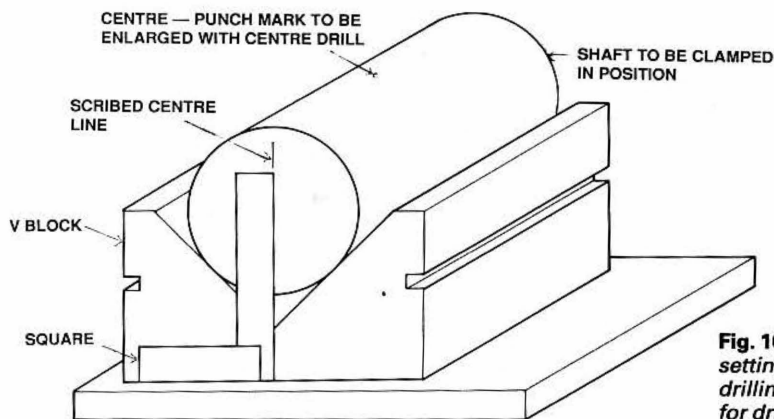
**Fig. 10.9** Machine vice for use with pillar drill etc.

being way off centre.

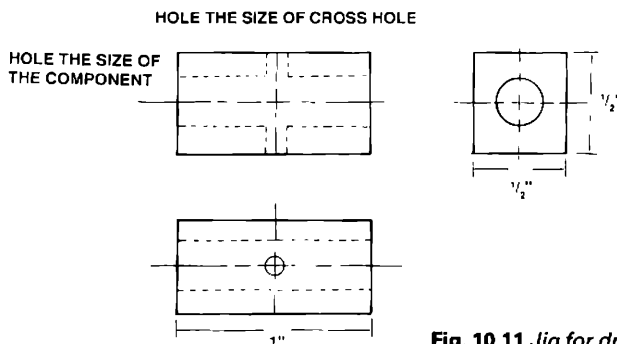
Using a jig is the ideal solution to this problem and a simple one will be described later. If a jig is not available a line is scribed across the exact centre of the end of the shaft in the way described in Chapter 9 on Marking Out. This line is then extended along the shaft. A centre-punch mark is then made on this line at the exact distance from the end of the shaft that the hole is to be drilled. The shaft is then clamped

in V-blocks and the scribed line on the end of the shaft is set truly vertical by means of a square. A small centre drill is used to enlarge the centre punch mark and to provide an accurate start for the drill used to form the hole. See Fig. 10.10.

A simple jig for cross-drilling can be made from a short end of  $\frac{1}{2}$  in. mild steel square bar as shown in Fig. 10.11. A hole of the same size as the required cross hole is drilled through the square



**Fig. 10.10** Method of setting shaft on drilling machine table for drilling cross hole.



**Fig. 10.11** Jig for drilling cross hole.

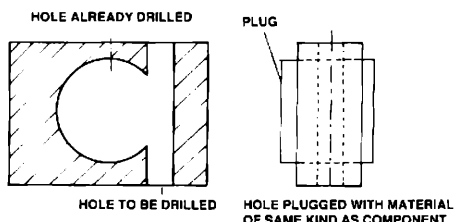
bar, great care being taken to ensure the hole is in the exact centre. Another hole is then drilled and reamed lengthwise through the bar to the exact size of the material through which the cross hole is required. Care must be taken to see that this hole is truly central. Having made the jig the material to be drilled is placed in position in the jig and the cross hole can be quickly and accurately drilled. End location of the cross hole is the only problem but careful measurement to calculate how much the shaft protrudes from the jig before drilling takes place should not be difficult. If a number of similar holes have to be drilled some form of stop, to locate the components accurately, should not be difficult to devise. Having made the jig it should be preserved as it is bound to come in useful on some future occasion. Over the years a number of these jigs will accumulate and provide a speedy and accurate method of doing a job which can be tedious.

Sometimes it is necessary to drill a hole to meet the side of a previously drilled larger hole. Unless special precautions are taken there is a danger of the unsupported drill being broken as it breaks through into the large hole. The best way to overcome this problem is to

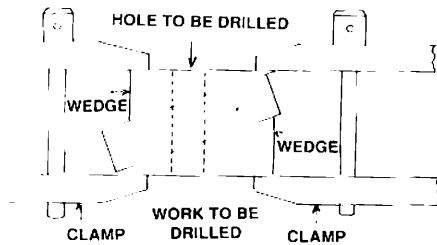
fit a plug, of the same material as that of the work, in the large hole so that the drill is supported throughout its travel. (See Fig. 10.12).

A similar difficulty arises when a drill has to be started on an inclined surface and the safest way in this case is to provide a wedged-shape piece of material with such an angle that the drill enters it at a right angle. When the hole has to go right through fairly thin material it may be possible to use two wedges held together by toolmaker's clamps, as shown in Fig. 10.13. If this is not possible some other means must be devised to hold the wedge in position.

Where two components have to be held together by nuts and bolts or by studs and nuts it is a good wheeze to drill the necessary holes while the two



**Fig. 10.12** Method of drilling hole into existing hole.



**Fig. 10.13** Drilling a hole on an inclined surface.

pieces are clamped together with tool-maker's clamps. Where studs and nuts are employed the tapping drill should be used first. The hole can then be tapped where necessary while the other hole or holes are opened out with a clearance drill.

Where the exact position of a hole is very important its location should be marked at the point of intersection of two crossed lines, scribed when the component is being marked out. A light centre-punch mark should be made exactly at the point the lines intersect. Accuracy can be checked by using a magnifying glass if there is any doubt that it is not 'spot on'. If the punch mark is slightly out it can be corrected by 'drawing' the mark over by using the centre punch at an angle. From the punch mark the circumference of the hole must be scribed with the dividers. The circle should then be lightly marked with centre-punch marks. A drill, smaller than the finished size, should then be used to start the hole. It can



**Fig. 10.14** Combination centre drill, sometimes called a 'Slocombe' drill.

then be seen if the drill has wandered and if the full size hole will correspond with the scribed circle. Any small error can be corrected at this stage by cutting a groove with a small diamond point chisel in the direction it is desired the drill should travel. This correction must be made before the drilled hole has reached its full diameter.

If sure that the centre-punch mark made initially is accurate a CENTRE DRILL, sometimes called a SLOCOMBE DRILL, Fig. 10.14, can be used to start the hole and entered up to the full diameter of its shank. The following drill will then be much less likely to wander because its cutting edge will be fully supported.

In all cases where large holes have to be drilled it is better to start with a small drill and then open out the hole with a larger drill. Drill chucks should be of good quality and drills should be held tightly in them. If the chuck does not hold the drill firmly then it is likely that the drill will jam in the work. The chuck will go on turning, scoring the shank of the drill and providing conditions where the drill may fracture.

Sometimes it is necessary to countersink a hole to take a countersunk screw. Commercial countersinks are expensive and are inclined to chatter unless run at very slow speeds. Often the lowest speed available on a drilling machine is not slow enough for this work. The single lip countersink, shown in Fig. 10.15, is easily made from silver steel, and avoids the chattering experienced with the expensive commercial tool. The flat cutting edge lies a little above the centre line of the tool. If the tool is made from  $\frac{1}{2}$  in. silver steel it is suggested that the cutting edge be made 0.005 in. above the centre line and this dimension should be checked with a

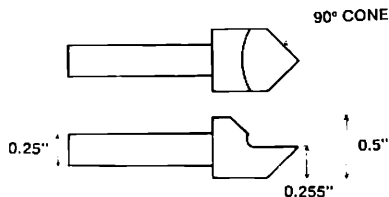


Fig. 10.15 Countersink.

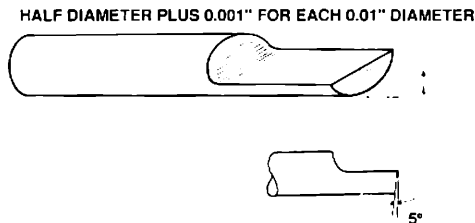


Fig. 10.16 D-bit.

micrometer. The tool should be hardened and tempered by heating to a bright cherry red and then quenched. The tool is then cleaned with fine emery cloth and the shank heated in a small flame until the tip assumes a straw colour when it is again plunged into cold water.

**D-bits** of the form shown in Fig. 10.16 will produce very accurate holes and they are easily made. A pilot hole, slightly smaller than the finished hole, is drilled and then opened out for a short distance with a conventional drill of the finished size. The D-bit is then used to produce an accurate size hole in much the same way as a reamer is used.

The tool is made from silver steel, filed to the shape shown in the drawing and then hardened and tempered in the same manner as the countersink in the previous paragraph. The flat surface behind the cutting edge must be a little above the centre line of the tool in order to maintain guidance as it is used. The cutting edge is finally honed to a fine finish.

**Reamers** are used for finishing drilled holes accurately in size and roundness. Fig. 10.17 shows a hand and machine reamer. The hand reamer, with which we are at present concerned, is distin-

guished from the machine one by having a square shank to carry a tap wrench and a taper lead for guiding it into the hole being reamed.

Obviously the drilled hole must be slightly, but only slightly, undersize so

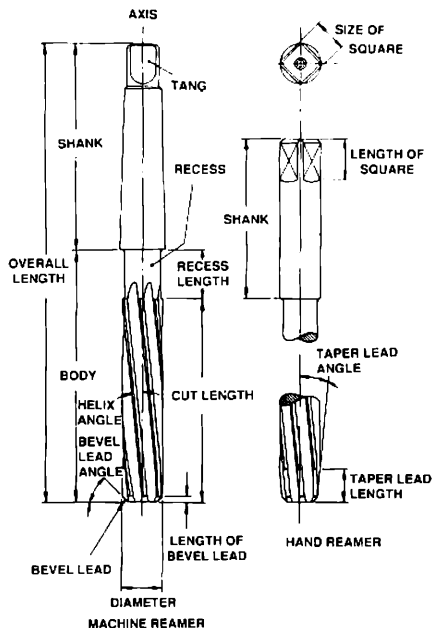


Fig. 10.17 Hand and machine reamers.

that there is metal left in the hole for the reamer to clear out. Reamers are intended purely as a finishing tool so very little metal should be left for the reamer to remove. For example a  $3\frac{1}{4}$  in. drill should be used when a  $\frac{1}{2}$  in. reamer is going to bring the hole accurately to size.

To use the reamer, the squared shank is gripped in a tap wrench and the tapered end of the reamer inserted in the hole to be reamed. The tool is then turned in a clockwise direction until it has passed fully into the hole. The reamer should be withdrawn from the

hole while still turning it in the same direction. The reamer must not be forced into the hole or roughly used as this may cause damage to the cutting edges. When steel is being reamed a plentiful supply of lubricant must be used. When a long hole is being reamed the reamer should be withdrawn from time to time to clear the chips from the flutes.

The machine reamer illustrated differs from the hand type in that it has less taper lead and is fitted with a Morse taper shank so that it can be used in machine tools.

## CHAPTER 11

# SCREWED FASTENINGS, SPANNERS, SCREWDRIVERS AND PLIERS

When components have to be dismantled and re-assembled from time to time, various types of screwed fastenings are employed. Where a permanent fixture is required riveting, soldering, brazing or welding are used. The permanent fixtures will be reviewed later.

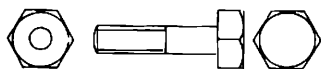
The simplest of the screwed fastenings is the NUT AND BOLT, illustrated in Fig. 11.1. The bolt in this case has a hexagon head and a portion under the head is left plain. The plain section extends beyond the joint face and there must be sufficient thread to allow the nut to seat tightly on the component.

The hexagon SET SCREW, Fig. 11.2a, is similar to the bolt but it is threaded right up to the head.

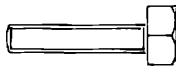
The STUD, Fig. 11.2b, is threaded at both ends; one end screws into the

component while a nut is used at the other end. When a stud is screwed into soft metal, such as aluminium, it is common practice for the thread at that end of the stud to be coarser than the end which carries the nut. This is because the coarser thread is less likely to strip than if a fine one was used. The fine thread at the nut end provides the clamping pressure needed. Incidentally, a nut with a fine thread is less likely to slacken off than one with a coarse thread.

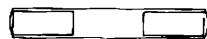
As well as the hexagon there are several different types of bolt and screw head to suit various applications. Some of these are illustrated in Fig. 11.3. A component is often counterbored so that a cheese-headed screw is below the surface. (see Fig. 11.4). The counter-



**Fig. 11.1** Nut and bolt. Bolt is only threaded part way.

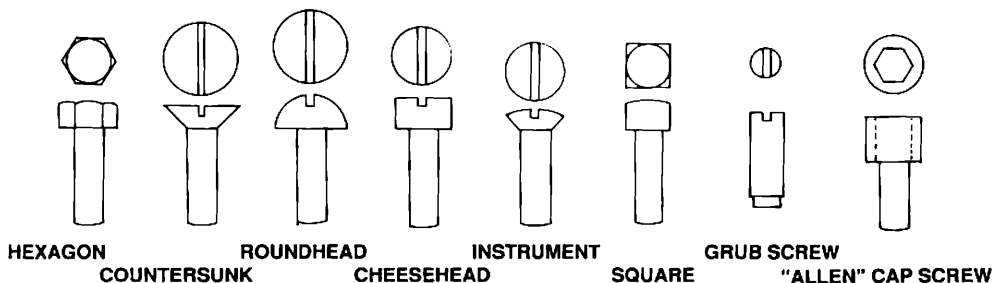


**Fig. 11.2a** Set screw. Threaded whole length.



**Fig. 11.2b** Stud. Threaded both ends.





**Fig. 11.3** Various types of screw heads.

sunk screw has an angle of  $90^\circ$  between the sides of its head and a special countersinking cutter is needed to machine the component into which the screw is going to fit.

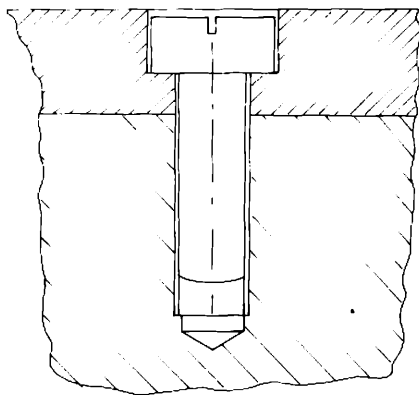
The GRUB SCREW has no head but is turned by a screwdriver fitted in a slot formed in the shank of the screw. It is often used as a locking device, typical examples being the securing of an electric cable in a terminal or the locking of a pulley on a shaft (see Fig. 11.3).

An extremely useful and versatile family of screws are those provided with hexagon sockets, popularly known

as 'Allen' screws. They are generally made of a high quality steel and have a hexagon shaped recess into which a special hexagon key fits for tightening or slackening purposes. They are available in cap, grub and countersunk types. The latter are very useful when fabricating components as they are flush fitting, very strong and can be tightened to a much greater degree than the ordinary countersunk screw with a screwdriver slot. A cap screw of this type is shown in Fig. 11.3.

It is often necessary to provide some method of locking a nut or set screw to prevent it slackening off. The degree of security necessary depends on the actual situation. For example, if a big end nut on an internal combustion engine comes adrift the result is pretty disastrous, while if a nut slackened off on an exhaust manifold on the same engine it would not be a very serious occurrence.

The most popular positive locking device is a SPLIT PIN passing through the slots in a STANDARD SLOTTED NUT or a CASTLE NUT and through the bolt itself (see Fig. 11.5a and b). Where a group of two or more set screws have to be locked a wire passing through holes in the heads of all of them, as shown in Fig. 11.5c, may be employed.



**Fig. 11.4** Counterboring to position cheesehead below surface.

The locking plate shown in Fig. 11.5d is another common locking device.

Self locking nuts (Fig. 11.5e) have a fibre ring inserted in the centre of the nut and a thread is cut in this ring when the nut is tightened. The fibre grips the thread on the bolt so that the nut is unlikely to become slack. They are less effective after they have been removed and in important locations they should be renewed once they have been removed.

Two nuts on a stud, as shown in Fig. 11.5f, are often used to prevent slackening off. The first nut is tightened to the correct torque and held by a spanner while the second one is tightened. When dismantling two spanners should be used initially, one to hold the bottom nut while the top one is

slackened. If this is not done there is a tendency for both nuts to move at once which might cause the thread to strip.

## SCREW THREAD NOMENCLATURE

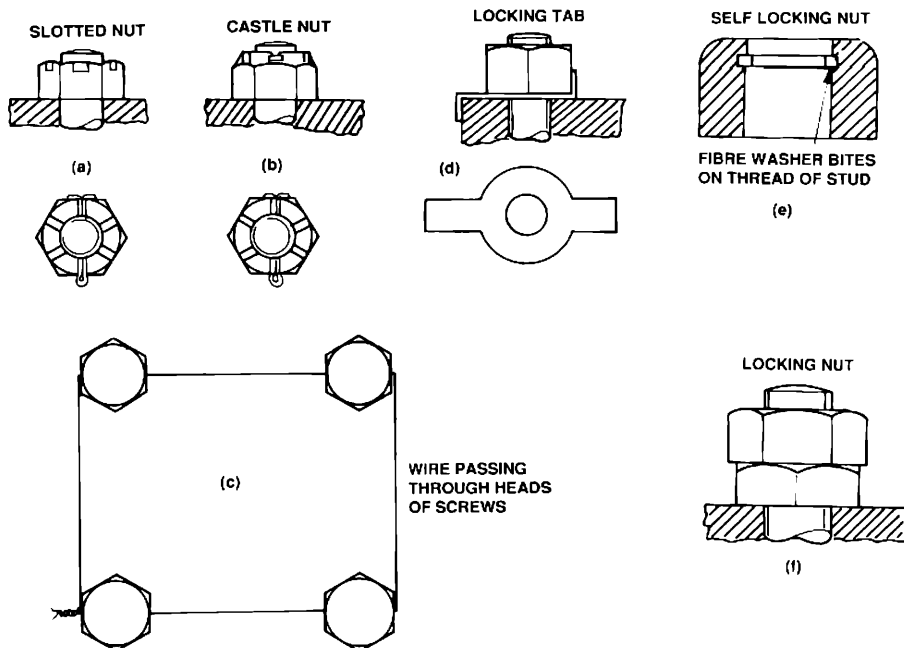
Before discussing the different thread systems the following definitions of screw thread terms will be useful:

**MAJOR OR OUTSIDE DIAMETER** is the distance across the thread measured at  $90^\circ$  to the thread axis,

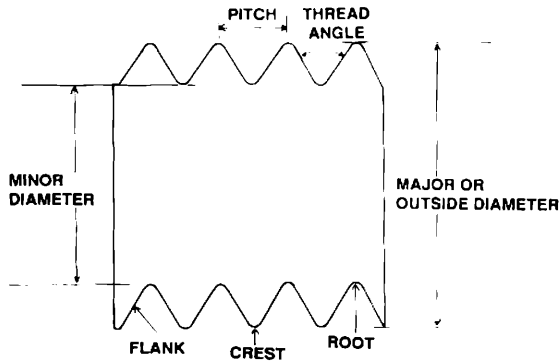
**THE CREST** is the tip of a thread where the two flanks join,

**THE FLANK** is the surface of the thread which connects the crest to the root.

**THE ROOT** of a thread is the bottom surface joining adjacent flanks,



**Fig. 11.5 Locking devices.**



**Fig. 11.5g** Thread terms.

**CORE OR MINOR DIAMETER** is the diameter of the thread measured across the roots.

**PITCH** is the distance from a point of a screw thread to a corresponding point on the next thread, measured parallel to the axis.

**LEAD** is the distance a screw advances axially in one turn. On a single start thread, used on ordinary bolts and screws, the lead and pitch are identical.

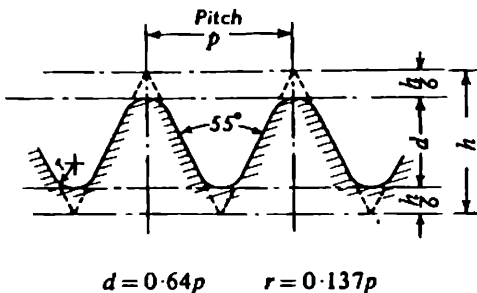
**THREAD ANGLE** is the angle enclosed by the flanks.

These terms are illustrated in Fig. 11.5g.

### SCREW THREAD SYSTEMS

Imagine the chaos which would arise if every manufacturer had his own thread system; repairing machinery would be a nightmare. Sir Joseph Whitworth, in 1841, realised that the work of engineers was greatly impeded by the lack of a thread standard and he instituted the system which bears his name. The form of this thread, known as the **BRITISH STANDARD WHITWORTH, (BSW)** is shown in Fig. 11.6. For some purposes this thread is too coarse and the **BRITISH STANDARD FINE** was introduced. This thread has the same form as the B.S.W. but with a finer pitch.

In 1945, following a series of conferences between Britain, America and Canada, the **UNIFIED THREAD** was introduced. There are two types, the **UNIFIED COARSE (UNC)** and the **UNIFIED FINE (UNF)**. The thread takes the form shown in Fig. 11.7 and it will be seen that the angle of this thread is  $60^\circ$



**Fig. 11.6** Whitworth and British Standard Fine threads.

as opposed to the 55° of Whitworth.

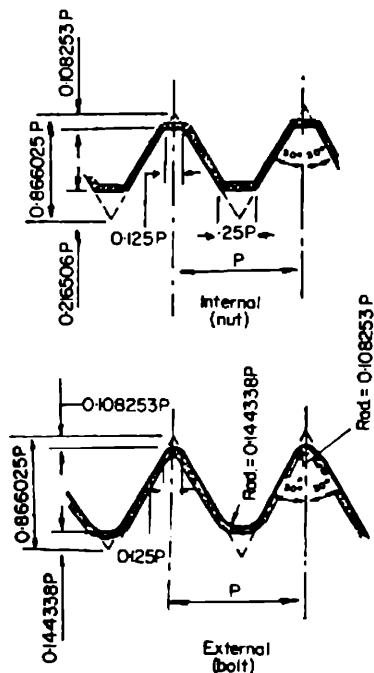
Spanners for the Whitworth sizes are designated according to the bolt diameter, for example the jaws of a ¼ in. Whitworth spanner fit a nut on a ¼ in. bolt but the jaws of the spanner are a little under ½ in. apart. Spanners for the Unified bolts are named according to the distance across the flats of the nuts which they fit and because of this they are known as 'AF' spanners, that is 'Across Flats' spanners.

In 1965 the President of the Board of Trade announced that British Industry should progressively adopt metric units and following this announcement the I.S.O. screw was introduced. It has the same form as the Unified thread, illustrated in Fig. 11.7 but, of course, the diameters are in metric sizes.

The BRITISH ASSOCIATION (BA) thread has been in use in the U.K. for many years for small screws, especially for electrical and instrument work. It is very popular with model engineers and is particularly suitable for their hobby. It has the form shown in Fig. 11.8 and the different diameters are designated as numbers ranging from '0', the biggest in the range with a diameter of 6mm, to the smallest, '23' with a diameter of 0.33mm. The usual set of taps and dies covers the sizes from 0 to 10. The number 10 screw has a diameter of 1.7mm (0.0669 in.), plenty small enough for most purposes.

The BRITISH STANDARD PIPE (BSP) thread is used chiefly for gas and water pipes but is sometimes used for other purposes where a fine thread is needed on large diameter work.

The BRITISH STANDARD BRASS thread is used for brass tubing, gas fittings and general brass work. The thread is of Whitworth form and all sizes have 26 threads per inch.



Unified thread form

- Basis of all modern vee threads
- UNC - unified coarse
- UNF - unified fine
- UNS - unified special
- ISO - metric

Fig. 11.7 Unified threads.

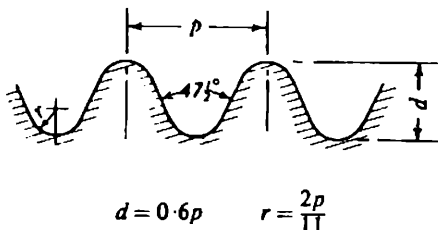
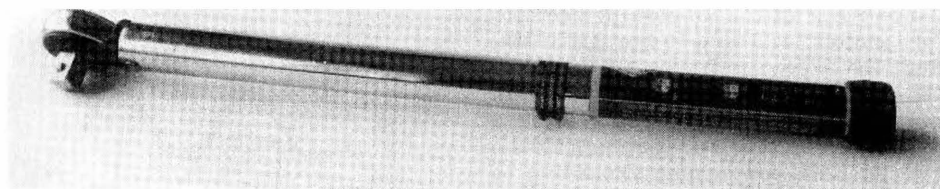


Fig. 11.8 British Association (BA) threads.



**Fig. 11.9** *Torque wrench.*

There is also a **MODEL ENGINEER** thread which has the same form as the Whitworth thread. Diameters up to  $\frac{1}{4}$  in. have 40 threads per inch (TPI). Above that size 32 T.P.I. is the norm although 40 T.P.I. are found sometimes on bolts above that size.

It is important that nuts and bolts are tightened to the correct torque. Torque, as far as nuts and bolts are concerned,

means the pull on the spanner that turns, or tries to turn, the nut or bolt. When a spanner is used to tighten a nut it acts as a lever and the torque equals the force applied to the spanner multiplied by the length of the spanner, the answer being given in Pounds Force Inches (lbf ins), Pounds Force Feet (lbf ft), Kilograms Force Metres (Kg fm) or Newton Metres (Nm) depending on which system is used.

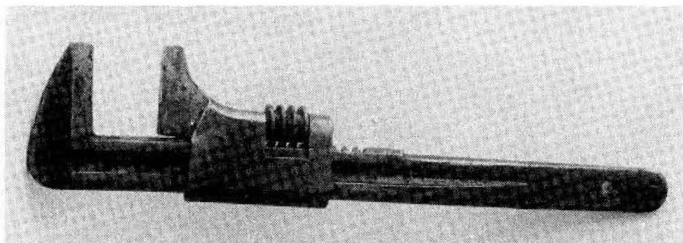
Many workshop manuals give the correct torque for tightening particular bolts and in these cases a torque wrench is used. A torque wrench has an adjustment which can be set, so that as a bolt is tightened and the required torque is reached, a loud metallic 'click' is heard. On hearing this 'click' one is assured that the bolt has been correctly tightened and no further action is needed. A torque wrench is shown in Fig. 11.9.

Where the bolt or stud is too small for a torque wrench to be used, or one is not available, the correct tightness has to be judged. The pull on the spanner should be smooth and on no account should it be jerked. It is important that the correct length spanner is used. Remembering that torque is the force applied multiplied by the length of the spanner, it will be seen that lengthening the spanner increases the torque even though the force applied remains the same.



**Fig. 11.10** *Different types of spanners.*

**Fig. 11.11 Adjustable spanner.**



## SPANNERS

There are various types of spanners to fit all the bolts and nuts described in this chapter. Fig. 11.10 shows those in general use. On the extreme left is the OPEN ENDED type. All spanners should be a good fit on the nuts on which they are used and this is particularly important with the open ended type. Because they only engage on two of the flats on the nut they are prone to slip off the nut when in use and, of course, if they are not a good fit this is much more likely to occur. Barked knuckles and rounded corners on nuts are the inevitable results of this malpractice.

A RING SPANNER is shown in Fig. 11.10, next to the open ended one. On these spanners the holes which accommodate the nuts are bi-hexagonal in shape, i.e. they have twelve corners and are, therefore, easier to use in a confined space, as they need only be turned one twelfth of a turn before they can be removed from the nut and re-engaged for a fresh pull. They also have the advantage of fully surrounding the nut which renders them less likely to slip off.

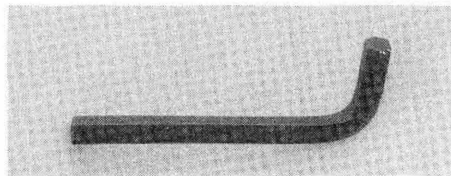
The COMBINATION SPANNER, to the right of the ring spanner in Fig. 11.10, has a ring at one end and is open ended at the other end. Open ended and ring spanners have different sizes at each end but combination spanners are supplied with both ends the same size.

Next in Fig. 11.10 is the SOCKET SPANNER, a short rigid tube having on one end an internal bi-hexagonal recess. The other end has a  $\frac{1}{2}$  in. square hole to take a handle. (Spanners with larger or smaller square holes are available for larger and smaller spanner sizes) A variety of handles is available including a brace or speed wrench, a hinged handle and a ratchet. Extension bars and a universal joint are also generally included in a set of this kind. A hinge type handle is shown adjacent to the socket in Fig. 11.10.

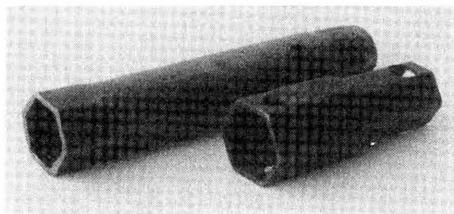
An ADJUSTABLE SPANNER is shown in Fig. 11.11. These have one fixed and one sliding jaw. Their use is not recommended if a fixed spanner of the correct size is available.

ALLEN KEYS are small 'L' shaped hexagon bars which fit into the recess of hexagon socket screws which were described earlier in this Chapter. See Fig. 11.12.

BOX SPANNERS, Fig. 11.13, have been largely superseded by the socket spanner but they are still useful for



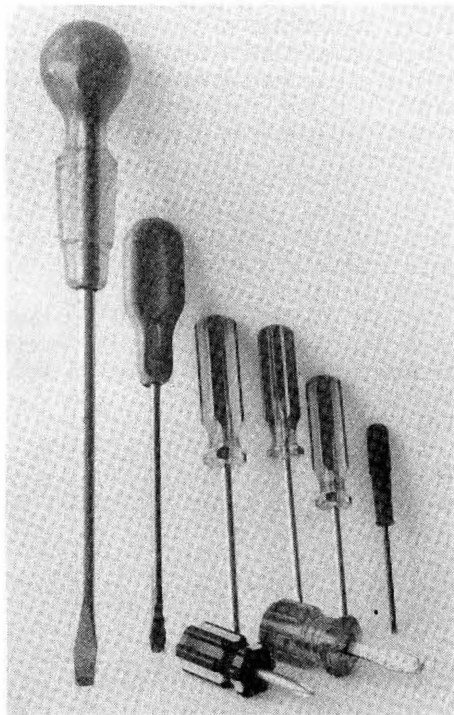
**Fig. 11.12 Allen key.**



**Fig. 11.13** Box spanners.

special jobs where a nut has to be tightened in a deep recess, or where the stud, for some special reason, protrudes a long way out of its nut.

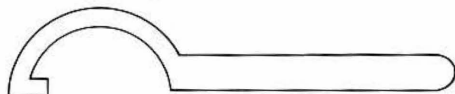
'C' SPANNERS, Fig. 11.13a, are used on fluted nuts sometimes fitted to pump or piston rod glands.



**Fig. 11.14** Various types of screwdrivers.

## SCREWDRIVERS

Good quality screwdrivers are made from chrome alloy steel suitably hardened and tempered. They vary in length from the 'stubby', made especially for working in confined spaces, to the very large ones, about 24 in. (610mm) long.



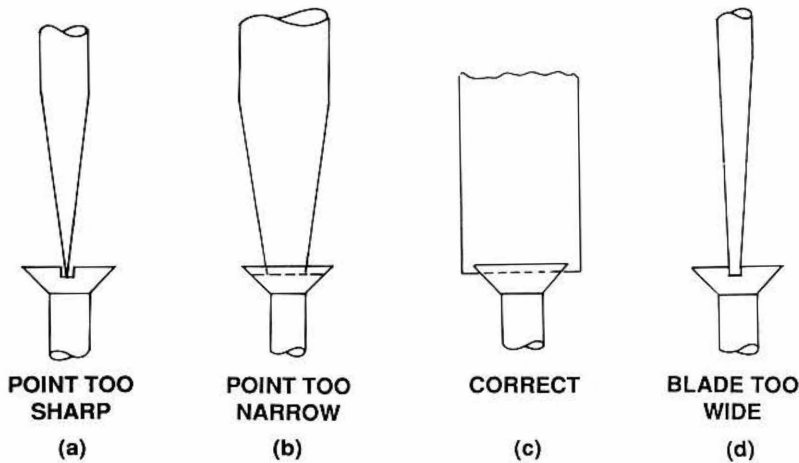
**Fig. 11.13a** C-spanner.

A variety of handles is available, but probably the best types for the engineer are those with tough, insulated, plastic handles. Fig. 11.14 shows a selection of various types.

Special screwdrivers are made for the Pozidriv and Phillips type screw heads. Although these are similar, in that they fit screws with a cross type head instead of a single slot, they are not identical. The Phillips type screwdriver will only give a poor fit on a Pozidriv screw and vice versa.

A screwdriver, like a spanner (for actually it is an internal spanner) should do its work by being applied, and then turned in the required direction, with the screw as its axis. If it is not properly formed and of the correct shape, it will require a great amount of pressure while being turned. Many amateurs experience troubles because their screwdriver is incorrectly sharpened and/or they are using the wrong type for a particular job.

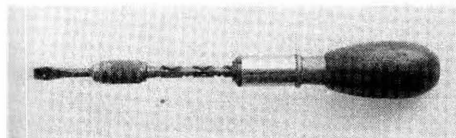
Fig. 11.15 illustrates correct and incorrect use of screwdrivers. At (a) the screwdriver has a sharp point and will be inclined to slip out of the screw slot. The screwdriver at (b) is too narrow for the screw and full pressure will be impossible to apply. At (c) the screw-



**Fig. 11.15** Correct and incorrect use of screwdrivers.

driver is too wide and when undoing a countersunk screw the edges will foul the sides of the work. At (d) the correct screwdriver, with the right shaped blade is shown.

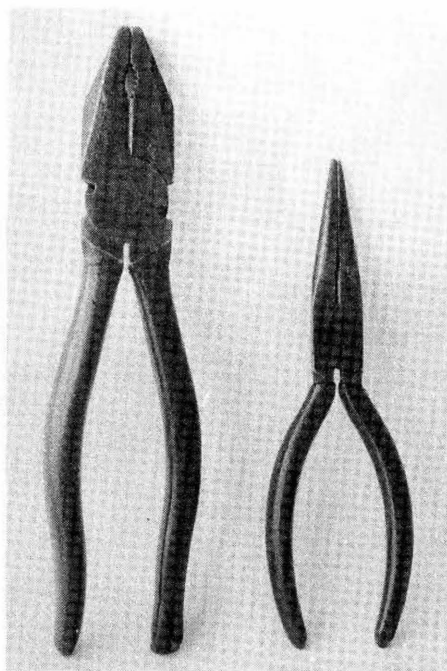
It is a strange fact that a long screwdriver moves a screw more easily than a short one, even though the mechanical advantage regarding the size of the handle and width of the point is the



**Fig. 11.16** Ratchet screwdriver.

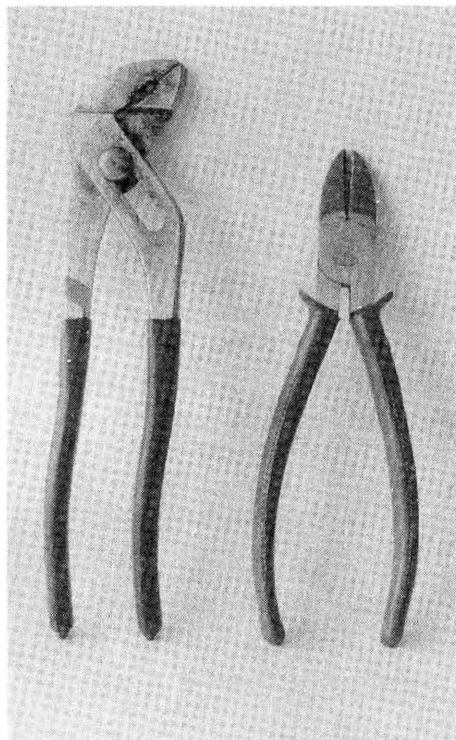
same. This may be because the operator can more easily apply his strength with the big tool than with a small one.

Ratchet screwdrivers speed up the work, especially on repetition work. One working on the Archimedean principle, which will insert screws using a downward movement of the handle, is illustrated in Fig. 11.16.



**Fig. 11.17** Side-cutters and long-nose pliers.





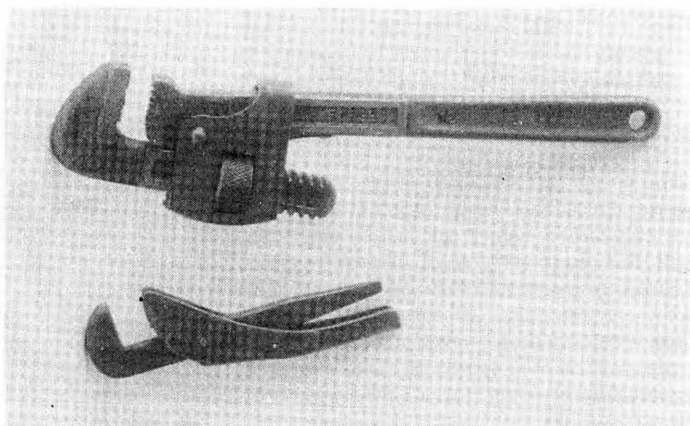
**Fig. 11.18** (above).  
Water pump pliers  
and side-cutters.

## PLIERS

Strictly speaking pliers should not appear in a chapter relating to screwed fastenings, as they should never be used to turn bolts or screws. It does seem convenient, however, to deal with them here, as they are classed as small tools which 'live' in the toolbox with spanners and screwdrivers.

A large variety of pliers is available but three or four pairs are all that are really necessary for ordinary work. The side-cutting and long-nose shown in Fig. 11.17 are the most useful types. The side-cutting pliers have serrated jaws and, at the inner end of the jaws, cutting edges. A shear type of wire cutter is arranged at each side of the rivet on which the pliers swivel.

The 'WATER PUMP' pliers, with a slip joint, is shown in Fig. 11.18 together with a pair of side-cutters, which are a useful addition to the tool kit. STILL-SONS and 'FOOTPRINTS', shown at Fig. 11.19, are used for pipework and turning other round materials. They should never be used on nuts or bolts as they have serrations which would cause serious damage.



**Fig. 11.19** Stillsons  
and 'Footprints'.

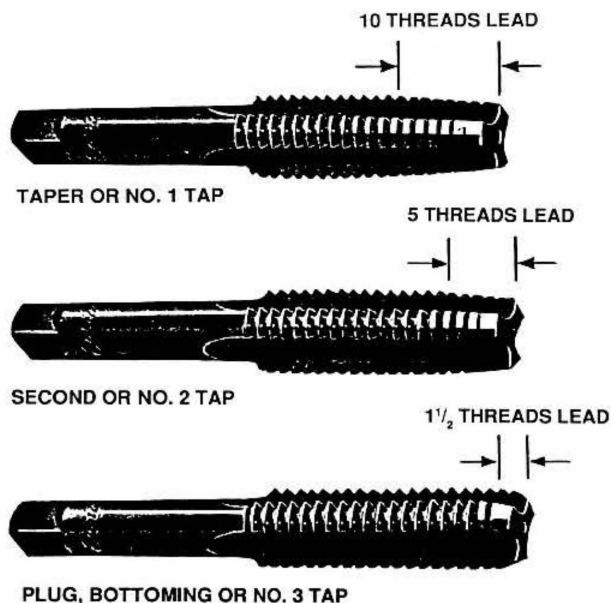
## CHAPTER 12

# TAPS AND DIES

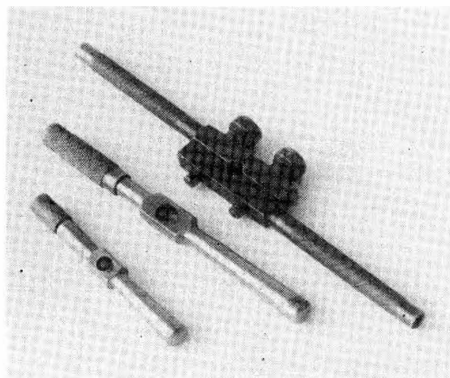
One of the basic skills an engineer has to acquire is producing external and internal threads by the use of taps and dies. Careless or improper use of these tools can cause endless trouble, as will be explained later.

TAPS for producing internal threads are supplied in sets of three, TAPER,

SECOND AND PLUG. (Fig. 12.1). The taper tap has fully defined screw threads only at the top end of the shank. The formation of the thread diminishes towards the lower end. The second tap is similar to the taper one but it has a longer length of fully defined thread with only a comparatively short length



**Fig. 12.1** Taper, second and plug taps.



**Fig. 12.2** *Tap wrenches.*

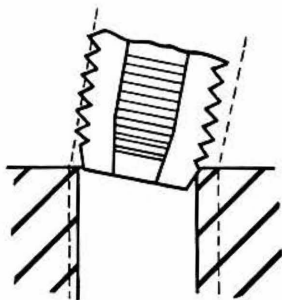
of taper. The plug tap has fully defined threads for practically its full length. The top end of the shank of the tap is square to accommodate a TAP WRENCH, examples of which are shown in Fig. 12.2.

For tapping, a hole must first be drilled to a diameter slightly greater than the core diameter of the thread. Published tables give recommended tapping drill sizes for various threads and the tables shown are taken from Neill Tool Users' Handbook, reproduced here by kind permission of Neill Tools Ltd. The tapping sizes recommended are for use only on steel and will give approximately 75% depth of thread. Deviations from stated tapping drill sizes will be necessary depending on the nature of the material and the requirement of the finished work.

It is unlikely that drills of the exact metric size given in the tables will in all cases be available. Often it will be found that a fractional or number drill, very near the recommended metric size, will do very well. For example a 2.7mm drill is recommended for tapping 5 B.A. A number 37 drill is very near this size and

will do the job very well. The torque required to turn the tap will depend on the size of the tapping drill: the smaller the drill the greater the effort required. This is an important consideration, especially with the smaller taps, if breakages are to be avoided. It may be better to use a drill at least one size larger than the one recommended if the resistance encountered when turning the wrench is excessive.

In the smaller sizes, likely to be used by the model engineer, taps are very likely to break off in the work and this is very frustrating, for not only has a new tap to be bought but the broken end of the tap has to be removed from the workpiece. This can be very difficult and sometimes almost impossible. The tap is hard, so it cannot be drilled out and some other means has to be devised. If part of the broken tap protrudes from the work it may be possible to grip it with a pair of pliers and screw it out, but I have never had much luck with this procedure. Some text books say it may be possible to screw the broken end out with light blows with a hammer and punch, but here again I have never found this to work. Sometimes, if the



**Fig. 12.3** *An oversize and bell mouth tapped hole will result if tap does not enter the hole squarely.*

### Tapping and clearance drill chart

These tapping drills are recommended for use on steel only and will give approximately 75% depth of thread.

Deviations from stated tapping drill sizes will be necessary, depending on the nature of material and requirements of finished work.

#### BA

Dia	Tapping	Clearance	Dia	Tapping	Clearance
0	5.10mm	6.20mm	7	2.10mm	2.60mm
1	4.50mm	5.50mm	8	1.80mm	2.30mm
2	$\frac{3}{32}$ "	4.90mm	9	1.50mm	2.00mm
3	3.50mm	4.20mm	10	1.40mm	1.80mm
4	3.00mm	3.70mm	11	$\frac{3}{64}$ "	1.60mm
5	2.70mm	3.30mm	12	1.05mm	1.40mm
6	$\frac{1}{32}$ "	2.90mm			

#### BS Fine

Dia	Tapping	Clearance	Dia	Tapping	Clearance
$\frac{3}{16}$ "	4.00mm	4.90mm	$\frac{1}{2}$ "	$\frac{7}{16}$ "	$\frac{33}{64}$ "
$\frac{7}{32}$ "	4.70mm	5.70mm	$\frac{9}{16}$ "	$\frac{1}{2}$ "	$\frac{37}{64}$ "
$\frac{1}{4}$ "	5.40mm	6.50mm	$\frac{5}{8}$ "	$\frac{9}{16}$ "	$\frac{41}{64}$ "
$\frac{9}{32}$ "	6.20mm	7.40mm	$\frac{11}{16}$ "	$\frac{5}{8}$ "	$\frac{45}{64}$ "
$\frac{5}{16}$ "	6.90mm	8.20mm	$\frac{3}{4}$ "	$\frac{43}{64}$ "	$\frac{49}{64}$ "
$\frac{3}{4}$ "	$2\frac{1}{4}$ "	9.80mm	$\frac{13}{16}$ "	$\frac{47}{64}$ "	$\frac{53}{64}$ "
$\frac{7}{16}$ "	9.80mm	$2\frac{9}{64}$ "	$\frac{7}{8}$ "	$\frac{51}{64}$ "	$\frac{57}{64}$ "
			1"	$2\frac{9}{32}$ "	$1\frac{1}{64}$ "

#### BS Whitworth

Dia	Tapping	Clearance	Dia	Tapping	Clearance
$\frac{1}{16}$ "	$\frac{3}{64}$ "	1.70mm	$\frac{3}{8}$ "	8.00mm	9.80mm
$\frac{3}{32}$ "	1.90mm	2.50mm	$\frac{7}{16}$ "	9.30mm	$2\frac{9}{64}$ "
$\frac{1}{8}$ "	2.60mm	3.30mm	$\frac{1}{2}$ "	$2\frac{7}{64}$ "	$\frac{33}{64}$ "
$\frac{5}{32}$ "	3.20mm	4.10mm	$\frac{9}{16}$ "	$\frac{31}{64}$ "	$\frac{37}{64}$ "
$\frac{3}{16}$ "	3.80mm	4.90mm	$\frac{5}{8}$ "	$1\frac{7}{32}$ "	$\frac{41}{64}$ "
$\frac{7}{64}$ "	4.60mm	5.70mm	$\frac{3}{4}$ "	$2\frac{1}{32}$ "	$\frac{49}{64}$ "
$\frac{1}{4}$ "	$1\frac{3}{64}$ "	6.50mm	$\frac{7}{8}$ "	$\frac{49}{64}$ "	$\frac{57}{64}$ "
$\frac{5}{16}$ "	6.60mm	8.20mm	1"	$\frac{7}{8}$ "	$1\frac{1}{64}$ "

*(continued on next two pages)*

right equipment is available, the tap can be heated and softened and then drilled out. This is another chancy technique and it is far better to be extra careful and avoid breaking a tap than to be faced with the task of removing a broken one.

As the action of tapping raises a swelling around the hole it is generally advisable to countersink a hole slightly before starting to tap it.

Having drilled and countersunk the tapping hole the taper tap is fixed to the tap wrench and started in the hole. In

**Tapping and clearance drill chart (continued)**  
**Unified**

Diameter	Tapping		Clearance
	UNC Coarse	UNF Fine	
0	—	3/64"	1/16"
1	1.45mm	1.50mm	1.95mm
2	1.70mm	1.80mm	2.25mm
3	5/64"	2.05mm	2.60mm
4	2.20mm	2.30mm	2.95mm
5	2.55mm	2.60mm	3.30mm
6	2.70mm	2.90mm	3/64"
8	3.40mm	3.50mm	4.30mm
10	3.80mm	4.00mm	4.90mm
12	4.40mm	4.60mm	5.60mm
1/4"	13/64"	5.40mm	6.50mm
5/16"	6.50mm	6.90mm	8.20mm
3/8"	9/16"	8.50mm	9.80 mm
7/16"	9.30mm	25/64"	29/64"
1/2"	27/64"	29/64"	33/64"
9/16"	31/64"	13.00mm	37/64"
5/8"	17/32"	14.50mm	41/64"
3/4"	16.50mm	11/16"	49/64"
7/8"	49/64"	20.50mm	57/64"
1"	7/8"	23.50mm	11/64"

order to avoid an oversize and bell-mouth tapped hole, caused by misalignment of the tap (Fig. 12.3), it is necessary to check that the tap is entering the hole squarely. This may be done with a small square as is shown in Fig. 12.4.

The bench drilling machine may be used for tapping holes if it is provided with a handle to turn the spindle while the tap is held in the chuck. This ensures that the tap is kept square with the work. Some years ago I built the

M.E. drilling machine but when I acquired a larger and more sophisticated machine I adapted the small one for tapping holes. (See Fig. 12.5)

Tap and dies should be lubricated when used on all materials except cast iron. A commercial grease is made especially for this purpose and gives excellent results. I have never felt the need to use a lubricant when working on brass but one leading manufacturer of screwing tackle makes the following recommendations:

METAL	LUBRICANT
Steel	Sulphurised oil
Cast iron	Dry or light soluble oil
Aluminium	Paraffin or mineral oil
Brass and copper	Paraffin and lard oil
Phosphor bronze	Lard or light oil

### ISO metric coarse pitch threads

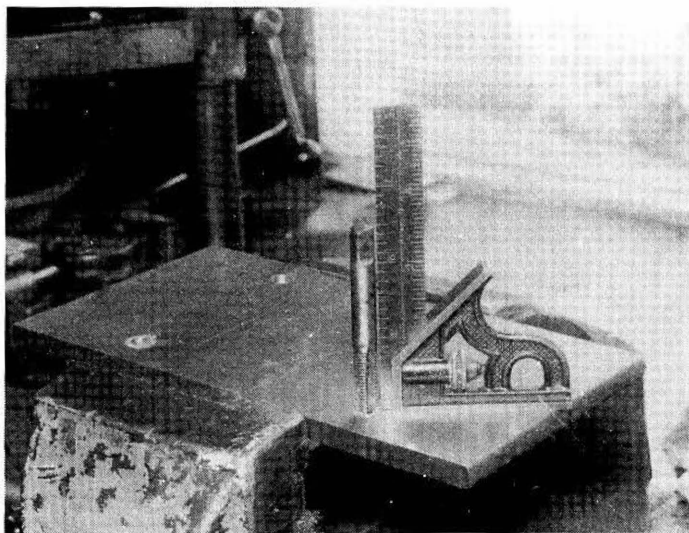
Dia	Tapping	Clearance	Dia	Tapping	Clearance
M1	0.78mm	1.1mm	M11	9.6mm	11.5mm
M1.1	0.88mm	1.2mm	M12	10.4mm	13.0mm
M1.2	0.98mm	1.3mm	M14	12.2mm	15.0mm
M1.4	1.15mm	1.5mm	M16	14.25mm	17.0mm
M1.6	1.3mm	1.7mm	M18	15.75mm	19.0mm
M1.8	1.5mm	1.9mm	M20	17.75mm	21.0mm
M2	1.65mm	2.2mm	M22	19.75mm	23.0mm
M2.2	1.8mm	2.4mm	M24	21.25mm	25.0mm
M2.5	2.1mm	2.7mm	M27	24.25mm	28.0mm
M3	2.55mm	3.2mm	M30	27.0mm	31.0mm
M3.5	2.95mm	3.7mm	M33	30.0mm	34.0mm
M4	3.4mm	4.3mm	M36	32.5mm	37.0mm
M4.5	3.8mm	4.8mm	M39	35.5mm	40.0mm
M5	4.3mm	5.3mm	M42	38.0mm	43.0mm
M6	5.1mm	6.4mm	M45	41.0mm	46.0mm
M7	6.1mm	7.4mm	M56	51.0mm	58.0mm
M8	6.9mm	8.4mm	M60	55.0mm	62.0mm
M9	7.9mm	9.4mm	M64	58.0mm	64.0mm
M10	8.6mm	10.5mm	M68	62.0mm	70.0mm

There are also ISO METRIC FINE PITCH THREADS but as these are many and varied, rather than present in table form it is suggested that the tapping drill is derived as follows:

Tapping Drill = Outside dia – Pitch e.g. 4.0mm dia 0.5mm pitch

Tapping Drill =  $4.0 - 0.5 = 3.5\text{mm}$

Clearance Drills as per table for COARSE PITCH THREADS.



**Fig. 12.4** Checking that tap is entering work squarely by using a small square.

When the taper tap is felt to have started its work and its squareness has been checked, cutting of the thread can proceed. The tap should not be turned continuously but about every half turn it should be reversed slightly to clear the thread. If any undue stiffness is encountered *no force whatever should be used* but the tap must be *very carefully* eased backwards to clear it.

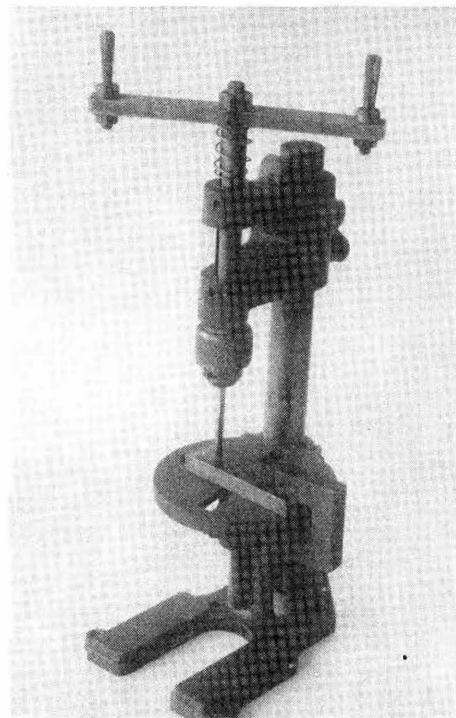
When a blind hole is being tapped the tap should be removed occasionally to clear the metal cuttings from the bottom of the hole. If the hole is a straight through one a reduction in resistance will indicate that the taper tap is cutting

a full thread. It can be removed from the hole which may be finished off with a second tap.

With blind holes resistance will be felt when the taper tap reaches the bottom of the hole. The tap is then removed and the second one taken down as far as possible. Finally the plug tap is used to cut the thread at the bottom of the hole.

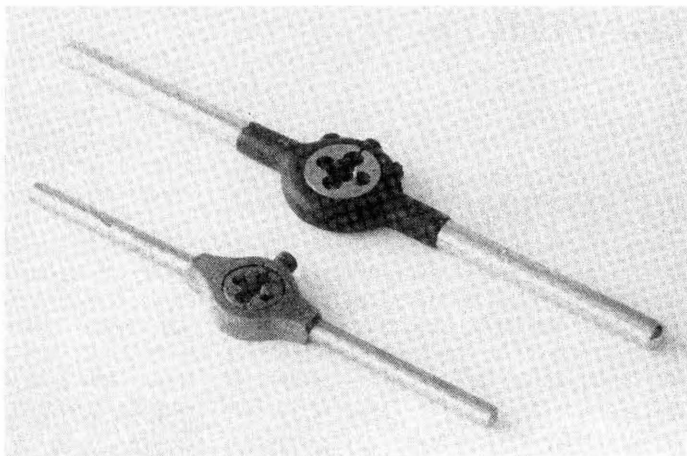
**STOCKS AND DIES.** The tool used for cutting external threads is known as a **DIE** and the device for holding the die is called a **STOCK**. The most common type of die is the split circular die shown in Fig. 12.6, fitted in a stock. The split permits limited adjustment in the size of the thread cut by the die. The ring portion of the stock into which the die fits contains three screws. The centre screw has a tapered end which fits in the split in the die. The other two screws press on to the periphery of the die. By slackening the two outer screws and tightening the centre one the die is expanded so that a shallower cut is taken. If the centre screw is slackened and the outer ones tightened then the die is squeezed in and a deeper thread is cut. Although the amount of adjustment is slight it is extremely effective in ensuring a good fitting thread.

Cutting an external thread with a die is a similar operation to using a tap and tap wrench but there is the problem of starting the die absolutely square. Generally only the first two threads of the die are chamfered and this does not give as much assistance as the long taper on a taper tap. Some stocks and dies are fitted with detachable collets which ensure the thread is cut squarely. There is a selection of collets and it is only necessary to find one of the correct size for the job in hand and place it in



**Fig. 12.5** Drilling machine adapted for tapping holes.

**Fig. 12.6** Circular stocks and dies.



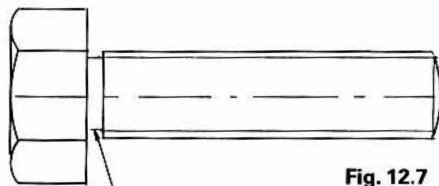
the stock and it will keep the die square with the work.

The following method of using dies is suggested:

- (1) Check that the rod diameter is correct and chamfer the end to give the die a start.
- (2) Spread the die with the centre screw so that a shallow cut is taken at first.
- (3) Check the die is square with the rod to prevent a 'drunken' thread being cut.
- (4) Close the die to the finish size by slackening the centre screw in the die stock and tightening the other two. Re-cut the thread to the correct depth.
- (5) Reverse the die stock every half turn to clear the swarf.

Dies must be lubricated in the same way as taps.

Sometimes it is necessary to cut a thread close up to the head of a bolt. Because the leading edge of a die is tapered a full thread is not cut up to the head of a bolt. This can be remedied, to a limited extent, by reversing the die in the stock after the thread has been cut, and then re-applying it to the bolt. The other and probably better way is to have a recess machined close to the head of the bolt, as is shown in Fig. 12.7. This recess should be at the same depth as the thread. If there is no objection to using a washer on the bolt it does not then matter that the thread is not cut to its full depth for its complete length.



RECESS CUT TO DEPTH OF THREAD  
SO THAT A FULL DEPTH IS AVAILABLE  
UP TO BOLT HEAD ALLOWING BOLT  
HEAD TO FIT FLUSH

**Fig. 12.7**



# CHAPTER 13

## RIVETING

Where a permanent connection in metal is required riveting is a satisfactory method of making a joint and is extensively used in boiler work, ship-building, on girders for building work, and in civil and general engineering.

On models, as well as making a secure joint the rivet heads must look right if a model is to appear authentic.

Rivets are made from any of the metals which are malleable and generally are of a similar material to that being joined. They are commonly made of steel, copper, brass and aluminium. Rivets made from the three latter metals are easily clenched because the metals are relatively soft; steel rivets may be riveted up hot or cold.

Fig. 13.1 shows the standard types of rivet heads. The round head is the most

commonly used; it gives maximum strength and is easily formed. Tin-smiths use the flat head rivet and I have found these, with a shank of about  $\frac{1}{8}$  in. diameter and  $\frac{1}{4}$  in. long, to be very useful, not so much for model making but for general work in the workshop, especially when welding facilities are not available.

Where the round head rivet cannot be used because the projecting head is an inconvenience the countersunk type enables a flush finish to be attained. The double countersunk, shown in Fig. 13.2, can be made from wire or rod, each end being riveted over and then filed flush. It is not necessary to have the same type head at each end of the rivet. For example, a round head rivet can be clenched with a countersunk

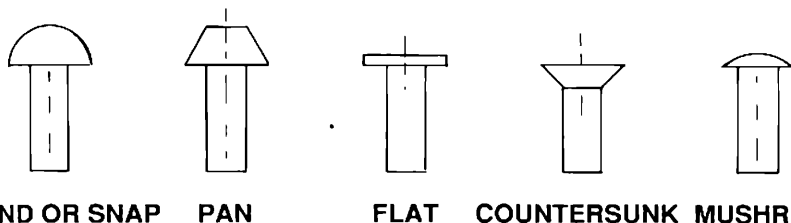


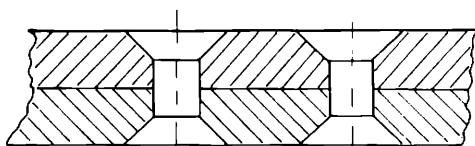
Fig. 13.1 Standard rivet heads.

finish if a smooth surface is required on one side of the plates being joined.

Riveted joints take various forms. Fig. 13.3a shows a lap joint and also illustrates the ideal spacing of rivets and the amount of overlap of the joint. Fig. 13.3b shows a butt joint and Fig. 13.3c a double riveted butt joint with cover plates on each side.

When joining two pieces of plate or sheet material the position of the rivets should be accurately marked out, as irregularly spaced rivets spoil the appearance of the work. Fig. 13.4 shows the rivets on the firebox end of a steam portable engine in the course of restoration, and it can be seen that as well as making a sound joint the rivets look right.

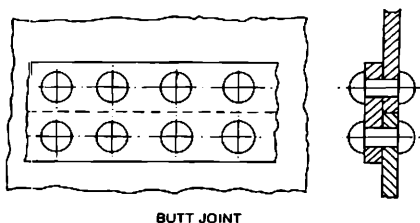
A line indicating the position from the edge of the work which the rivets will occupy can be scribed with odd leg calipers (jennies) and the pitch centres



**Fig. 13.2** Double countersunk rivets can be used where a flush finish is necessary.

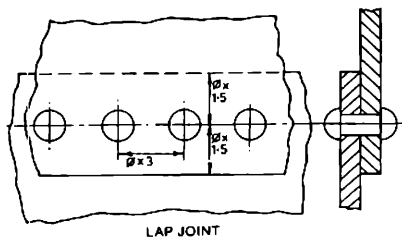
of the rivets marked off with dividers and then with a centre punch.

If possible the plates forming the joint should be clamped together with the top plate marked out for the holes as described above. The holes may be drilled through both plates at once so that the holes are bound to align, making the insertion of the rivets easy. The order in which the holes are drilled will depend on the nature of the work. In some cases it may be advisable to drill two holes at the ends of the work and secure the plates together with nuts and



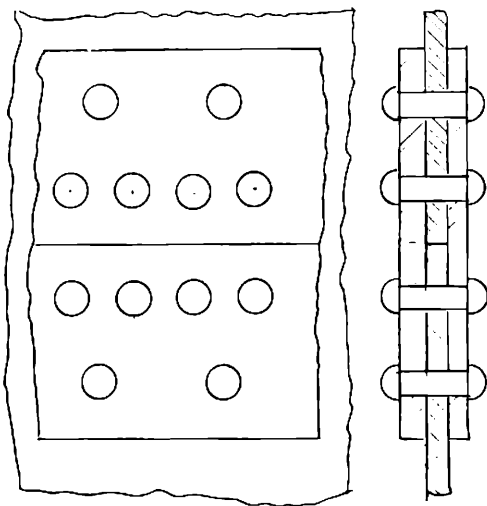
BUTT JOINT

**Fig. 13.3b**

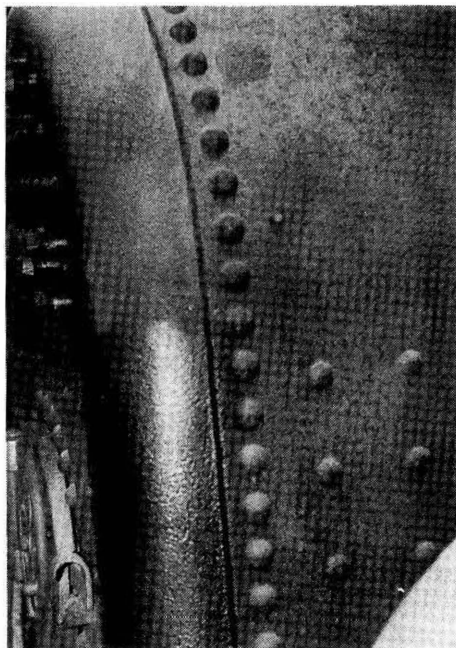


LAP JOINT

**Fig. 13.3a**



**Fig. 13.3c** Double riveted butt joint with cover plates both sides.



**Fig. 13.4** Rivets on the firebox of a portable steam engine.

bolts. Further holes can then be drilled and rivets inserted and clenched. When the plates are fully secure the bolts can be removed and rivets inserted in their place.

It is important that the correct size rivet is chosen. A general guide to rivet diameter is to make  $d = 1\frac{1}{2} t$ , where  $d$  = rivet diameter and  $t$  = the thickness of the plates to be joined. For thin plate this rule may give too small a rivet so the rule must be used with discretion.

The correct length rivet must be selected; if it is too long or too short the rivet snap cannot form the correct shaped head. As a general rule the length of a rivet should be  $1\frac{1}{2}$  times the diameter plus the thickness of the mat-

erials being riveted for a round head rivet and the diameter of the rivet plus the thickness of the materials for the countersunk one.

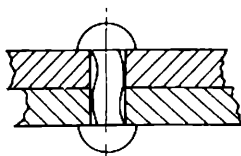
Rivet holes must be of the correct size. If the holes are too large the rivets will tend to bend over instead of expanding to form a nice tight fit. If the holes are too small the rivets can only be inserted with difficulty and the edge of the hole may shear the sides of the rivets so that the head will be unable to bed properly (see Fig. 13.5).

Rivets may be clenched in two ways, with a round head or countersunk. When a round head is required the procedure illustrated in Fig. 13.6 is followed. A tool with a rounded recess in its head, to fit the head of the rivet, is gripped in the vice. The closing tool, basically a punch with a hole in its end slightly larger than the shank of the rivet, is used to ensure the rivet head is tight against the work and that the two pieces of plate have no gap between them. The shank of the rivet is then given a few well directed blows with the hammer, the aim being to swell the rivet shank in the hole and at the same time rivet over the tail. Finally the rivet is finished to shape with the rivet snap. During all these operations the rivet head remains seated on the tool gripped in the vice.

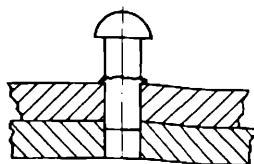
Many riveting failures arise through a beginner over-hammering a rivet, that is employing a number of slight, feeble blows when two or three heavier ones would suffice. The rule is that the fewer the number of blows delivered to close down a rivet the more closely will it secure the joint and the softer and more ductile the metal remains.

In most of the work done by model engineers and also in general engineering small rivets are riveted while cold. It

**Fig. 13.5**  
Correct size  
holes are  
important.



**HOLE TOO LARGE**



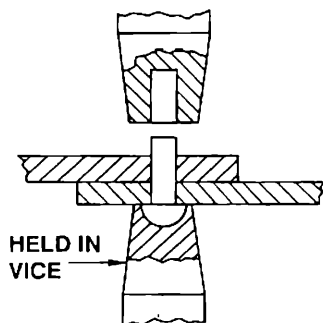
**HOLE TOO SMALL**

is only in the larger sizes that rivets are clenched hot. The advantages of hot riveting lie in the fact that less violence is needed to form the head, so that the plating is not so severely stressed, and that the contraction of the hot rivet, as it cools down, tends more effectively to close up the joint.

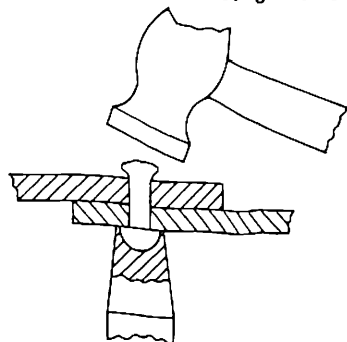
If a flush finish is required each rivet hole may be slightly countersunk and the rivet shank expanded into the countersunk portion of the work. Too

deep a countersink will entail unnecessary hammering to expand the rivet and should be avoided. After the rivet has been firmly clenched it can be filed flush and it should then be almost invisible. Care must be taken not to bruise the metal around the hole when riveting as this can be very unsightly.

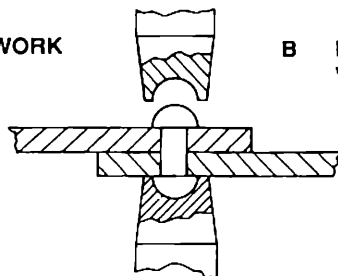
The holding-up tool, colloquially known as a 'dolly', the rivet snap and the closing tool can all be easily made from silver steel. The closing tool only



**A CLOSING THE WORK**

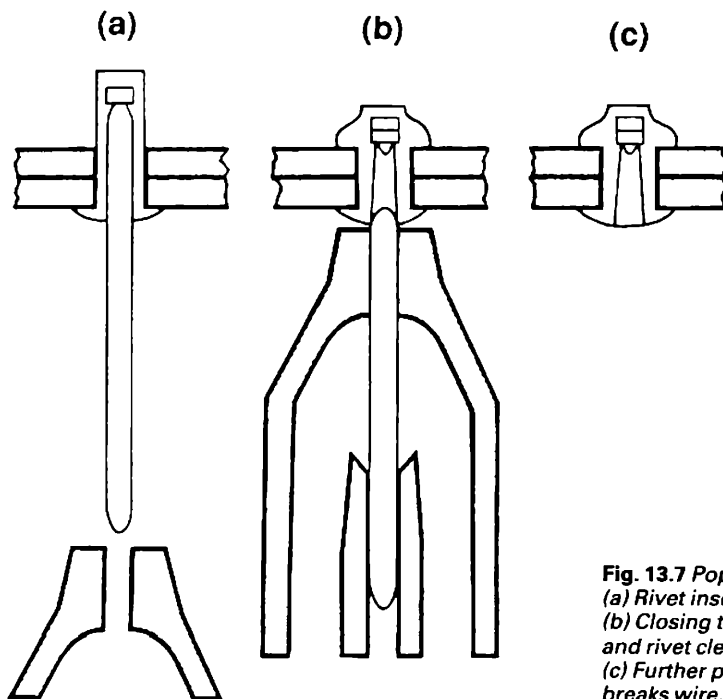


**B EXPANDING THE RIVET  
WITH HAMMER**



**C FINISHING HEAD WITH RIVET SET**

**Fig. 13.6 Stages in riveting.**



**Fig. 13.7 Pop rivets**  
 (a) Rivet inserted  
 (b) Closing tool applied  
 and rivet clenched  
 (c) Further pressure  
 breaks wire.

needs a hole drilled in its end deep enough to take the rivet shank, but for the other two it is necessary to make a special form tool to machine the recess to take or form the rivet head. Alternatively if a hardened steel ball of the same diameter as the rivet head is available, this can be used to forge the right shape. A hole should be drilled in the end of a piece of silver steel of a suitable diameter for a depth slightly less than half the diameter of the ball. The steel should then be heated, the ball placed in the hole and given a smart blow with the hammer. This treatment should provide a recess the same shape as the rivet head. All three tools must be hardened and tempered.

The support afforded to the rivet during riveting is most important because if it is not of a solid, unyielding nature a satisfactory job cannot be achieved.

'Pop' rivets, illustrated in Fig. 13.7, where the design of the component prevents a dolly being used to support the rivet, are used extensively in industry. The rivet is specially constructed with a wire running through its centre. This wire is pulled by a special closing tool to clench the rivet.

Bifurcated rivets, where the shank is divided into two legs, and hollow rivets are used for light work but these cannot be expected to give as satisfactory a joint as a solid one.

## CHAPTER 14

# SOFT SOLDERING

Soft soldering is a very useful method of making joints in most metals and particularly in copper, tin, brass, steel and tinplate and for joining electric cables. Aluminium cannot be soldered using the conventional methods. Soldering is not a satisfactory medium where much strength is required or where the joint is subject to vibration or heat as a soldered joint is comparatively weak and solder has a low melting point. Where a permanent joint is

required and the joint must stand up to heavy loads or high temperature, riveting, brazing or welding should be used.

The solder I am discussing goes under the general name of TINMAN'S SOLDER, an alloy of tin, lead and antimony. It is sold in sticks about 400mm (16 in.) long and roughly triangular in section. British Standard 219:1959 gives a list of solders, their content and other properties and the following table sets out those in general use.

BS219	Tin%	Lead%	Antimony%	Melting Range Solid/Liquid °C		Properties and Use
A	65	34.4	0.6	183	185	Electrician's solder for wiring electrical components liable to damage if heated.
B	50	47.5	2.5	183	204	Coarse Tinman's solder, a cheap grade for general use.
C	40	57.8	2.2	183	227	General work, cheaper than 'B'.
F	50	49.5	0.5	183	212	For electrical work and zinc.
K	60	39.5	0.5	183	188	A free running, quick setting solder for high class work.

Grade 'C' is suitable for general work but Grade 'K', which has minimal anti-mony content, is recommended for fine work, particularly model engineering projects. It has a shorter melting range, penetrates joints more readily and is easy to use. It is slightly more expensive than the other grades but is worth the extra outlay.

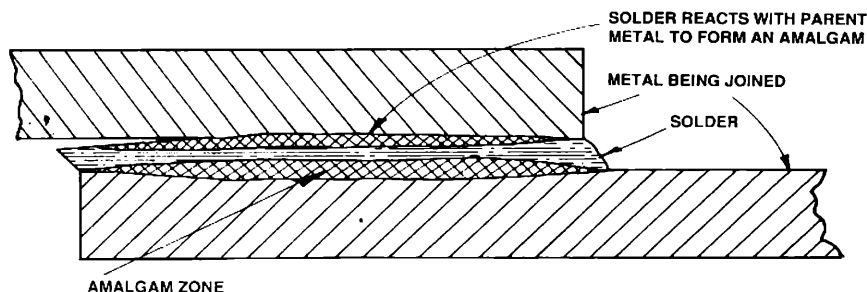
When a good soldered joint is made a section through the joint appears as in Fig. 14.1. The solder reacts with the parent metal to form an amalgam. For this intimate union to take place between the metal and the solder the surfaces of the joint must be scrupulously clean. If molten solder is placed on a dirty surface it will not wet the surface of the metal but will remain in a globular state. The dirt and an oxide film prevent the close contact necessary for the solder to spread over and wet the surface.

Cleaning may be done with emery or sandpaper, by filing or with wire wool. One authority warns that emery cloth should not be used on soft metals, such as copper, unless the surface is subsequently scraped all over, because particles of emery become embedded in the surface and may prevent the solder

adhering properly. I have never experienced this trouble but pass the information on for what it is worth.

When heated the surface of the joint will be attacked by the oxygen in the air and a flux is used to keep the air away to prevent oxidation, and to destroy the oxides by chemical action. An illustration, taken from a very old booklet published by the Tin Research Institute, reproduced in Fig. 14.2, shows how the flux is displaced by the molten solder.

There are two kinds of fluxes, those which not only protect the surface but play an active part in cleaning it and those which only protect a previously cleaned surface. The first type is the more efficient, zinc chloride being the one generally used. This is made by dropping zinc cuttings into spirits of salt (hydrochloric acid) contained in a stone jar. This zinc bubbles up and dissolves and the solution is then ready for use. When I was an apprentice I was sent to the local chemist for the spirits of salt. In those days there were no domestic refrigerators but most homes had a 'meat safe', a cupboard with a perforated zinc door and sides to allow for ventilation but to keep out the flies. Scrap ends of the perforated zinc were



**Fig. 14.1** Section through a soldered joint shown in exaggerated form.

- A FLUX SOLUTION LYING ABOVE OXIDISED METAL SURFACE
- B BOILING FLUX SOLUTION REMOVING THE FILM OF OXIDE (E.G. AS CHLORIDE)
- C BARE METAL IN CONTACT WITH FUSED FLUX
- D LIQUID SOLDER DISPLACING FUSED FLUX
- E TIN REACTING WITH THE BASIC METAL TO FORM COMPOUND
- F SOLDER SOLIDIFYING

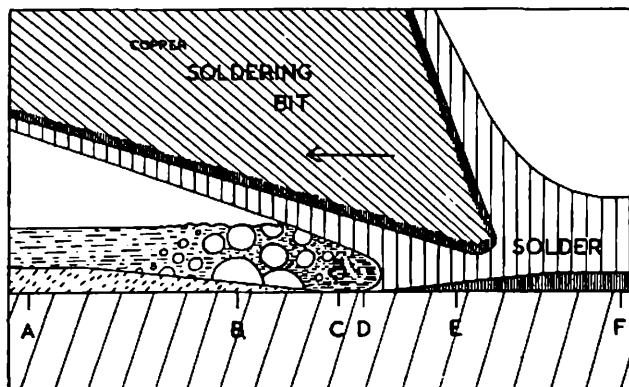


Fig. 14.2 Diagrammatic representation of the displacement of flux by molten solder.

always available and small pieces were dropped into the spirits of salt in a lead container kept for this purpose.

I only described this method as a matter of interest as there is now a commercial product on the market, Baker's Fluid, which can be bought relatively cheaply and which is all ready for use. I keep a small quantity in a shallow china jar, which originally contained meat paste, and which is ideal for this purpose.

There is a big snag with this acid type flux: it is *highly corrosive* and joints made with its use must be thoroughly washed with hot water when completed, or dipped in a weak alkaline solution such as ammonia, to neutralise the acid. There is no guarantee that all the flux will be expelled when the solder runs into the joint and any remaining therein could cause serious corrosion. The vapour given off when using the acid type flux is objectionable and does cause rusting on any ferrous metals nearby. If at all possible, and weather permitting, I do my soldering outside the workshop in the open air,

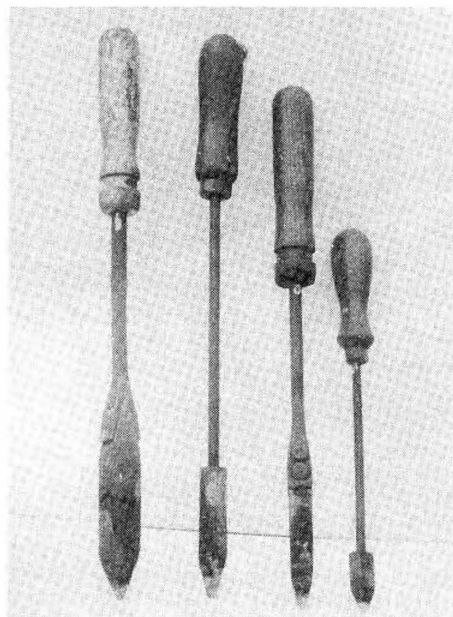
well away from my machine tools. In spite of these drawbacks to the acid type flux, it is the most effective in use and if its corrosive nature is always borne in mind, and suitable precautions taken, it is very suitable for many jobs.

The second type of flux has only very moderate cleansing properties but does prevent oxides forming and is effectively non-corrosive. It must be used where washing off is not practical or where subsequent corrosion cannot be tolerated. This type of flux should always be used, for example, for joining electric cables. Resin, turpentine and Vaseline (Petroleum jelly) form the basis of these fluxes, Fluxite being one of the commercially available products.

For small electrical joints CORED SOLDER, where the flux is carried in a hollow wire of solder, so that it can be applied simultaneously with the solder, is very convenient.

For most work a soldering iron is used: 'iron' is a misnomer as the 'bit', the business end of the tool, is made of copper. This metal is used because it is a very good conductor of heat and rap-





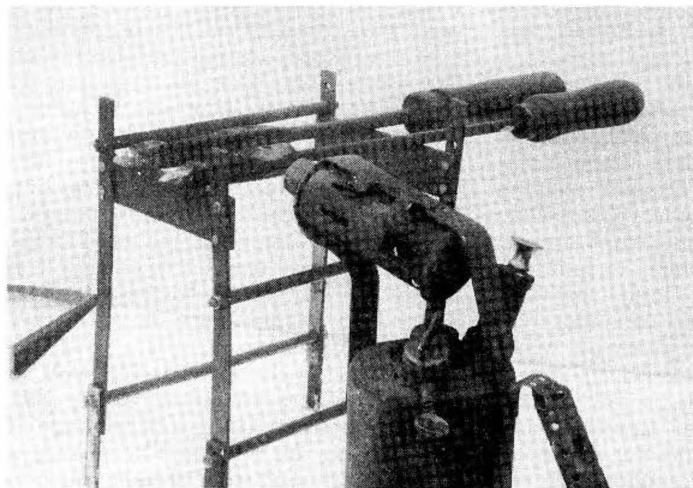
**Fig. 14.3** *Solid copper soldering irons.*

idly transfers heat from the iron itself to the work, and it readily alloys with tin. This latter property allows the tip of the iron to be 'tinned', that is given a coating of solder. A selection of soldering irons appears in Fig. 14.3.

The most convenient way of heating an iron is on a gas heater. In industry a rectangular gas heater, covered by an iron box, is used, the copper bit being placed in the box in the flame. If this special facility is not available any form of gas 'ring' will do. I have no gas supply in my workshop and I use a paraffin blow lamp with a simple stand to carry the irons as shown in Fig. 14.4.

Electric irons, as shown in Fig. 14.5, are available and are useful for small work, particularly for soldering electric cables. For heavier work I find the ordinary iron, heated as described above, far superior. It is an advantage to have two irons so that one can be heated while the other is being used.

The first operation is to 'tin' the iron. This is done by heating it to a high



**Fig. 14.4** *Paraffin blow lamp with stand for heating soldering irons.*

temperature, but less than red heat. The tip is then quickly cleaned with an old file and then dipped in the flux. If the temperature and other conditions are right when the tip is rubbed with solder it will take on a thin film of solder. I find an easy way of doing this is to pour a small drop of Baker's Fluid on to a tin; an old biscuit tin lid is ideal. If the hot and clean iron is then rubbed in the flux and solder applied a lovely bright silver coloured surface appears on the tip. When in this condition it must not be overheated otherwise the tinning process will have to be repeated.

When making a lap joint the minimum overlap is three times the thickness of the metal. The optimum solder film is 0.003 in. See Fig. 14.6. Both the surfaces to be joined must be cleaned and tinned. Assuming Baker's Fluid is being used, this can be done by dipping the solder stick in the flux and then applying the solder to the iron, flux being added to the surface being soldered as required. The iron must be held in close contact with the work for long enough for the heat to be transferred to the work, as it is only when the work is really hot that the solder will run freely.

When both surfaces have been tinned they are placed together after adding a little flux. The iron is then moved over the joint causing the tinning to melt and

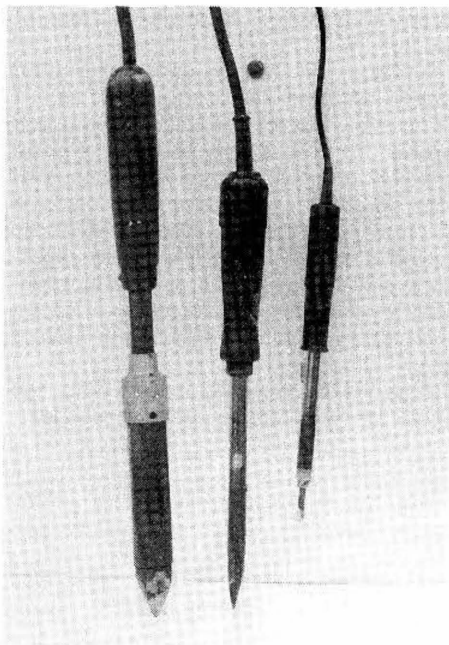


Fig. 14.5 Electric soldering irons.

to fuse the two materials together. A little extra solder can then be run along the edges of the joint to give added strength and a neat appearance.

A thick layer of solder between the two metals being joined does not make the joint as strong as where a small amount is used. As stated earlier, the

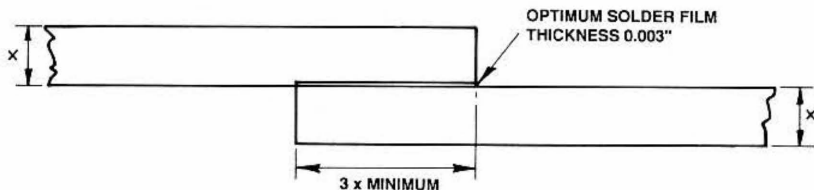


Fig. 14.6 Lap joint minimum dimensions.

optimum thickness of solder in the joint is 0.003 in.

As large an iron as can be handled should be used and it should be as hot as possible but, of course, not red hot. If you doubt your ability to make a good joint try yourself out on two pieces of scrap material and then, having made the joint, pull it apart to establish how sound a job you have made. All workshop skills can only be gained by practice; in this case make sure of clean work and a hot iron when you 'have a go'.

A word of warning concerning the repair of tanks which have contained a

flammable liquid such as petrol. Every care must be taken to ensure every trace of the liquid and its vapours are expelled from the tank before any heat is applied. Ideally the tank should be steam cleaned but if this is not possible it should be filled with water, shaken and then 'topped' up with more water. It should then be shaken again and again 'topped up'. This process should be repeated until no more water can be added and it is certain that no pockets of flammable vapour remain. *This must be done before any heat is applied* even if the tank is an old one from which it appears all the fluid has evaporated.

## CHAPTER 15

# SILVER SOLDERING, BRAZING, BRONZE WELDING AND ENGINEERING ADHESIVES

**Silver Soldering** is similar to soft soldering except that the operation is carried out at a much higher temperature and the resulting joint is much stronger.

Silver solder is an alloy and alloys seldom have an exact melting point; because of this silver solders are described as having a *melting range*. The solder will be solid at a temperature below the lowest figure quoted, the *solidus*, and liquid above the higher temperature, the *liquidus*.

Easy-flo silver solder, complying with B.S. 1845 AG1, supplied by Johnson Matthey Metals Ltd., is made up of 50% silver, 15% copper, 16% zinc and 19% cadmium. It has a melting range of 620° – 630°C.

Easy-flo silver solder No 2, complying with BS 1845 AG2, contains 42% silver, 17% copper, 16% zinc and 25% cadmium and has a melting range 608° – 617°C.

Easy-flo contains more silver than Easy-flo No 2 and consequently costs more. Its higher silver content gives Easy-flo somewhat higher ductility in the cast condition, better corrosion resistance, and it provides neater joint fillets than can be obtained with Easy-

flo No 2. There is no practical difference in the melting temperatures or in the melting ranges of the two alloys. Easy-flo No 2 is recommended in all cases, excepting those where maximum ductility is essential, where the smoothest fillets are desired, or where the corrosion conditions of service are severe.

**Fluxes.** Because of their low melting temperatures Easy-flo solders should not generally be used with relatively high-melting point brazing fluxes based on borax or borax acid. For the best results, use should be made of Easy-flo flux, except for special cases.

It is important that a gap is left in the joint into which the solder can run by capillary action. There **MUST** be a gap for the solder to penetrate if a proper joint is to be made. A gap of 0.001 in. (0.025mm) is the minimum required and double this figure is more likely to be satisfactory.

Cleanliness of the parts to be joined is essential in both brazing and silver soldering. The surfaces to be joined must be rendered free from dirt, rust and grease by filing, scraping or grinding.

Where a paste flux is used, and this

type is recommended, it should be smeared on the joint before placing the two pieces together. If the flux is in powdered form a small quantity should be mixed into a paste and used in the same way.

The actual way in which silver soldering is tackled will depend on the type of heat available and the size of the job to be tackled. Some form of blow-pipe is essential. The oxy-acetylene welding outfit, described in the next chapter, can be used for this purpose. Excellent results can be obtained with the Primus-Sievert L.P.G. appliances or even with the humble paraffin blowlamp.

Clamps may be necessary to hold the pieces to be joined in position while the soldering is carried out. Toolmaker's clamps, 'G' clamps or wire may be used for this purpose. Tubal Cain, in his admirable book 'Simple Workshop Devices', describes an easily made little gadget for holding delicate pieces of work in position.

Having rendered the joint scrupulously clean and smeared it with paste flux, the work is heated until it is hot enough to melt the solder, which will then run into the joint.

Pickling, that is immersing in acid, is not necessary for the removal of most brazing fluxes. The work should be quenched from black heat in warm water, when most of the flux will crack or dissolve. Sulphuric acid pickle will remove oxide or scale and hasten flux removal. The best proportion for the pickle is one part of concentrated sulphuric acid to ten parts of water. Old battery acid is not recommended as it may contain lead sulphate, which may react on the work. When making this solution the *acid must be carefully and slowly poured into the water* and not

water into the acid. This is because the mixing of the two liquids produces considerable heat. If the acid is added to the water the mass of water absorbs the heat. If the water is added to the acid the heat produced will cause the acid and water to be thrown out of the vessels with such violence that the person doing this mixing is virtually certain to receive acid burns. Diluted acid can be obtained from some chemists and it is better to purchase it in this way than have the trouble and risk of mixing it. Even diluted acid is dangerous – it will burn holes in clothes, and it must be used with great care.

**Brazing**, a similar process to silver soldering, is where metal parts are joined by flowing melted brass, known as SPELTER, between the surfaces to be joined. A much higher temperature than that required for silver soldering is necessary, a red heat as high as 850°C being required. The process cannot be used, of course, where the metal to be joined has a lower melting point than the spelter.

**Borax** is the flux generally used, a small quantity is made into a paste with water and applied to the parts to be brazed before heating. The rest is kept dry for use during the operation.

**Bronze Welding.** Although this term is in general use it is something of a misnomer. It is not true fusion welding because the metals joined are not heated to melting point. It cannot be correctly described as brazing because brazing involves capillary attraction of the filler metal into a narrow joint.

Bronze welding involves the use of alloy bronze rods and is used for making joints in copper, for joining dissimi-

lar metals, and for repairs to cast iron. It is essential that the edges of the materials being joined are not melted but merely raised to red heat. For example, when bronze-welding cast iron, Saffire manganese bronze rod should be used, melting at 890°C, well below the melting point of cast iron.

## **ENGINEERING ADHESIVES**

In recent years a very large range of adhesives has been made available to the engineer and many of them have been put to uses which the older engineer never thought possible. For example, it is possible to use an adhesive to retain a component in position instead of using an interference fit. This has the advantage of eliminating the stress which an interference fit causes and allows machining tolerances and surface finishes to be eased. This method has been used to retain all the parts of an aluminium racing cycle frame and the main column of a milling machine.

**Epoxy Adhesives.** These come in two tubes, one containing an adhesive and the other a hardener. When mixed together, in equal quantities, a chemical reaction occurs between the two which results in a very hard and strong bonding between the joint faces to which they are applied. Araldite is probably the most famous of this type and it is supplied in two kinds. The original type takes twenty four hours to cure at a temperature of 20°C., but can be handled after three to five hours if kept at room temperature. More recently a 'rapid' version has become available which has a much quicker initial set. This type has the disadvantage of a very short life as a usable 'mix', so it has to be applied very quickly. Joint faces must be clean and grease-free.

**Anaerobic Adhesives.** These adhesives have the peculiar property of remaining fluid until air is removed from them. As soon as the fluid is smeared on to two surfaces and the surfaces are brought together the fluid begins to harden or cure. The components to be joined must be free from all traces of dirt and grease. This cleaning can be done using a rag soaked in white spirit or petrol (take the usual precautions against fire). Washing with a detergent and water is also helpful. A good grip is obtained in about two hours but full strength is not obtained for about twelve hours.

Special types are available for thread-locking, making gaskets, sealing pipe connections and for bonding a variety of materials.

**Cyano-Acrylate Adhesives** are very fast curing compounds, marketed by one company under the name 'Super-glue'. They set within seconds. Care is needed in their use as drops spilt on human skin bond almost instantly. If this occurs, for example, if the fingers get stuck together, they may be carefully peeled apart. Deposits on the skin should be washed in warm soapy water and the deposit peeled off. It is advisable to wear goggles when using this type of adhesive.

As with the other types of adhesives, cleanliness of the parts to be joined is important; they should be washed in a detergent and water.

There are many different adhesives available, each excellent for the particular purpose for which they are designed, and it is vitally important to study the maker's specification charts to ensure that the type most suitable for the job in hand is used. Loctite and Permabond are two companies specialising in this field.

# CHAPTER 16

## WELDING

The art of welding has been known and practised for many centuries but until relatively recent times the only practical method of making a weld was by heating the two pieces to be joined, at the point where the joint was to be made, then, when they were almost at fusing point, placing them together in their proper relationship on an anvil and completing the weld by hammering. This process is known as **FORGE WELDING**.

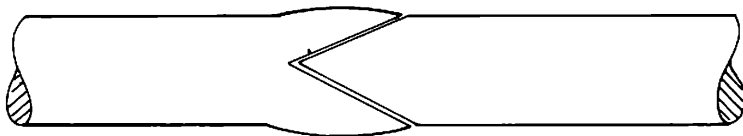
This technique is unlikely to be available to the amateur because, generally, he has insufficient heat available to

bring the metal to the required temperature. Blacksmiths are the experts in this type of welding and a forge, similar to the one they use, is almost essential. Before looking at the more common forms of welding a brief look will be taken at what this older type of welding has to offer.

Wrought iron and mild steel are the metals which can be welded in this way. The welding heat for iron is at a temperature of about  $1350^{\circ}\text{C}$ , when the metal is white hot and bordering on the pasty stage. Mild steel is welded at a slightly lower temperature when its colour is



**Fig. 16.1a** *Scarf weld.*



**Fig. 16.1b** *V or splice weld.*

yellow and before merging to white. It is important that welding is done at the right temperature, as if it is too low no amount of hammering will cause the weld to take place while if the temperature is too high the metal will be burnt.

The scarf weld, Fig. 16.1a, is the most straightforward to carry out and the most often used. After the ends of the joint have been prepared they are heated to welding heat and then hammered together to complete the weld.

The 'V' or splice weld is a very strong job and is preferred where the thickness of the metal permits preparation of the 'V'. One of the pieces to be joined is thickened up and then split with a hot chisel to form the 'V'. The other piece is forged to the shape shown in Fig. 16.1b which shows the two pieces ready for welding.

### OXY-ACETYLENE WELDING

If suitable proportions of oxygen and acetylene gases are mixed together and fed through the nozzle of a blowpipe, the combined gases, when ignited, rapidly generate intense heat. The heat can quickly bring metals up to temperatures at which they can be successfully joined – or welded – together.

The acetylene and oxygen are stored in high pressure cylinders fitted with regulators to reduce the high pressure to the considerably lower pressure required for the operation of the blowpipe.

Murex Welding Products Ltd., ESAB Group (UK) Ltd, supply a lightweight portable oxy-acetylene welding set, known as the Portapak, a photo of which appears in Fig. 16.2.

Acetylene cylinders are painted maroon and contain a porous substance and a solvent for the gas. They are charged at pressures corresponding

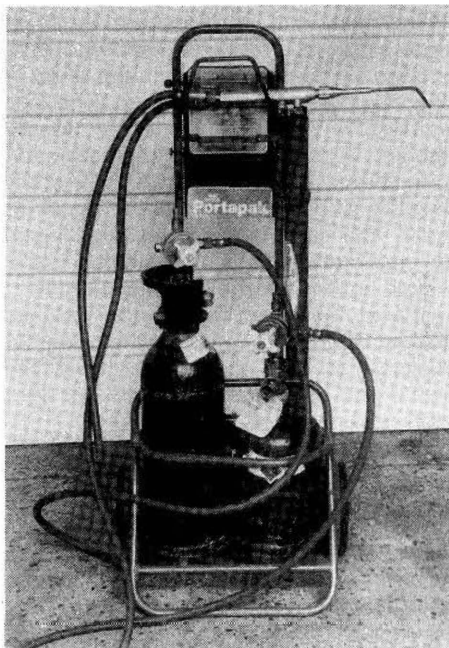


Fig. 16.2 Portapak welding set.

to 225 lbs/in<sup>2</sup>. Because acetylene cylinders contain liquids, *they should always be stored and carried upright*. All acetylene fittings have left hand threads so it is impossible to connect them, in error, to the oxygen cylinders. The acetylene hoses are red in colour.

Acetylene is a highly flammable gas and if allowed to mix with air is likely to explode if ignited by flame, heat or spark in the vicinity. See therefore, that all joints, especially those at the cylinder valve which are under high pressure, are gas tight, hose in good condition, and gases turned off at the cylinders when work is finished. Do not test for leakage with a flame; use soapy water.

If an acetylene cylinder leaks at the



gland round the valve spindle, the leakage can usually be corrected by tightening the gland nut. If the cylinder leaks at the valve or the base plug, and the leak cannot be remedied by firmly closing the valve, the cylinder should be moved into the open away from fires, electric motors and such sources of spark or heat. The suppliers should be advised immediately. Forbid smoking and naked lights near the leaking cylinder.

If acetylene from the cylinder catches fire at the valve or regulator due to leakage at the connection, shut the valve and make the joint properly tight before further use.

*Action in the event of a fire in which cylinders are involved.* Gas cylinders should always be treated carefully but experience has shown that they are in fact high integrity packages which withstand considerable abuse from users. If, however, they are subject to extreme heat in a fire, they can explode. The following is good advice to anyone faced with the situation of a fire in which gas cylinders are known to be involved.

Keep everyone well clear until the Fire Brigade arrives to take control.

Inform the Fire Brigade immediately of the location and type of any gas cylinders involved in the fire. Also tell them the location and type of other gas cylinders in the premises.

Cylinders which are not involved in the fire, and which have not become heated, should be moved as quickly as possible to a safe place, providing this can be done without undue risk. Make sure cylinder valves are closed.

Cylinders in the fire should be cooled by spraying with copious quantities of water over the entire exposed surface. Personnel engaged in this should take up positions which will give protection from exploding cylinders.

Great caution should be taken after the fire has been extinguished as there is still the possible danger that cylinders affected by heat could explode.

(Action in the event of a fire reproduced by kind permission of B.O.C. Ltd).

Oxygen cylinders are painted black and are fitted with blue hoses. (Older sets may have black hoses). There is no porous mass or liquid in them. NEVER, UNDER ANY CIRCUMSTANCES, allow oil or grease to come into contact with oxygen fittings. Oxygen escaping from a leaking hose will form a flammable mixture with oil or grease and may cause clothing and other articles to take fire vigorously from a spark.

The blowpipe for the Portapak is shown in Fig. 16.3. A key is provided to open the cylinder valves and they should be opened slowly. Sudden, rapid opening may cause damage to the regulators.

After consulting the data chart pro-

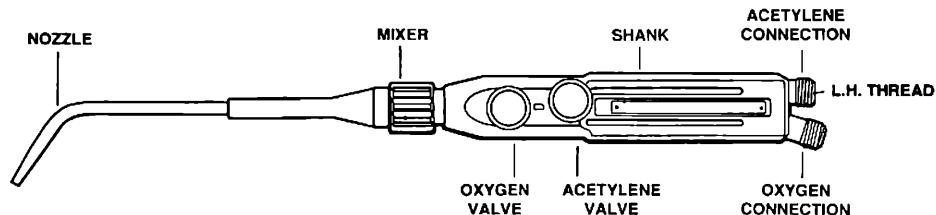


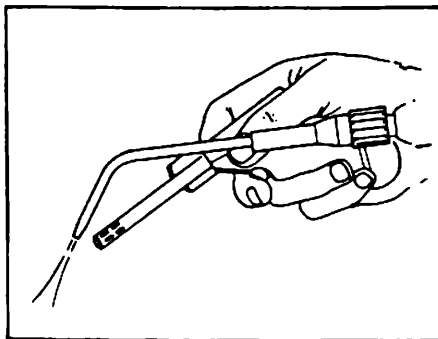
Fig. 16.3 Welding blowpipe.

vided the oxygen regulator is adjusted to the required working pressure. This must be done with the blue oxygen valve on the blowpipe open. This valve is then closed and the acetylene working pressure is adjusted in the same way.

A small quantity of gas is then fed through each hose to clean the passages. This must be done one at a time, ensuring one valve is closed before opening the other one.

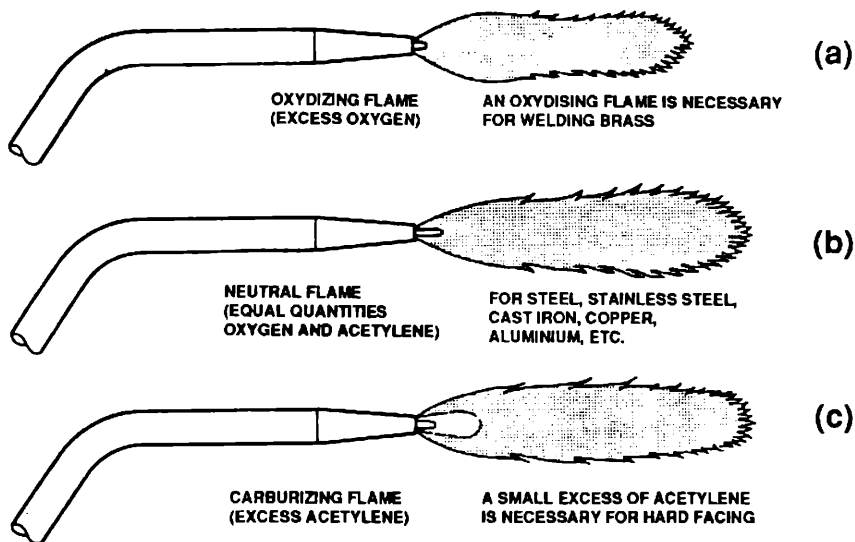
A spark gun is supplied with the outfit and after opening the red acetylene valve slightly the spark lighter is held facing along the direction of the flame at the end of the nozzle and the gas is ignited. (See Fig. 16.4). The flame is adjusted by opening the red acetylene valve until the flame ceases to smoke. The blue oxygen valve is then gently opened.

Three types of flame can be obtained.

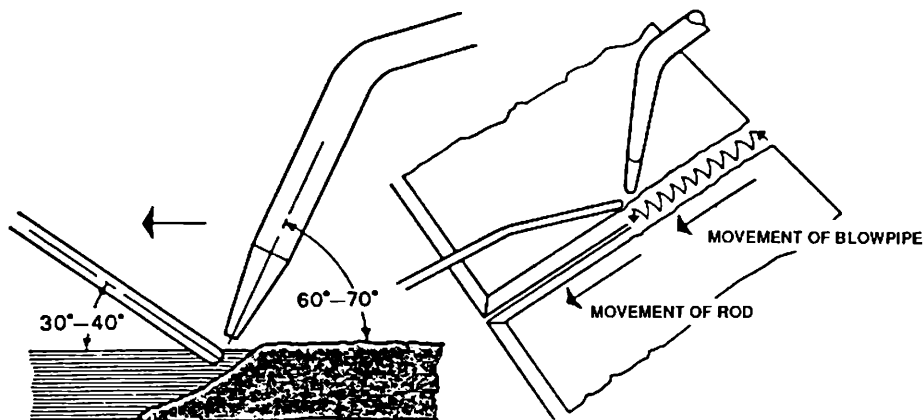


**Fig. 16.4** *Lighting the flame.*

For welding steel, cast iron, copper and aluminium a neutral flame is necessary; this is where equal amounts of oxygen and acetylene are being burnt at the same rate and will be evident by the white cone being clearly defined with the merest trace of acetylene haze (See Fig. 16.5b).



**Fig. 16.5** *Types of oxy-acetylene flames.*



**Fig. 16.6** *Leftward welding.*

For bronze welding an oxidising flame is required and this is obtained by increasing the amount of oxygen. The flame then appears as is shown in Fig. 16.5a. For hard facing and certain other specialised applications a carburizing flame is required and this is obtained by increasing the flow of acetylene until a haze or feather of acetylene is evident at the end of the white cone. (See Fig. 16.5c).

**LEFTWARD WELDING.** Welding is a specialised subject and it is not proposed to discuss the various techniques in great detail. Leftward welding is the most commonly used method and is used on steel for flanged edge welds, for unbevelled plates up to 3.2mm ( $\frac{1}{8}$  in.) and for bevelled plates up to 4.5mm ( $\frac{3}{16}$  in.). It is also the method usually adopted for cast iron and non-ferrous metals.

Welding is started at the right-hand edge of the joint and proceeds towards the left. The blowpipe is given a forward motion with a slight sideways move-

ment to maintain melting of the edges of both plates at the desired rate and the welding rod is moved progressively along the weld seam – see Fig. 16.6.

This form of welding differs from that used by the blacksmith in that the edges of the metal being joined are actually made molten and fuse together. Any lack of metal in the join is made up by a filler rod, of the appropriate material, which is melted in the seam as the weld progresses.

**RIGHTWARD WELDING** procedure is recommended for steel plate over 5.00 mm ( $\frac{3}{16}$  in.) thick. Plates from 5.00mm to 8.00mm ( $\frac{3}{16}$  in. to  $\frac{5}{16}$  in.) need not be bevelled. The weld is started at the left of the seam and proceeds towards the right as shown in Fig. 16.7. The blowpipe flame precedes the filler rod in the direction of travel. The rod is given a circular forward motion and the blowpipe is moved steadily along the weld seam.

Special filler rods and fluxes are required for metals other than mild

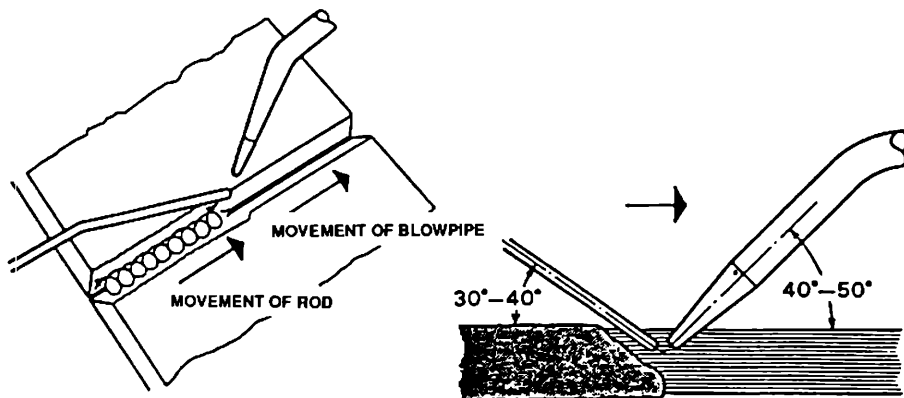


Fig. 16.7 Rightward welding.

steel. For all but the smallest cast iron articles, it is necessary to pre-heat the metal before welding and to allow very gradual cooling after the weld has been completed, to allow for the effects of expansion and contraction as the temperature varies.

Goggles, supplied with the equipment, must always be worn to protect the eyes from dangerous sparks and rays. Quite apart from the safety aspect the goggles enable the workpiece to be seen more clearly.

### METAL CUTTING PROCESS USING OXY-ACETYLENE GAS

It is possible to cut steel with an oxy-acetylene outfit by changing the welding blowpipe for the cutting one shown in Fig. 16.8. The chief difference in the two is that on the cutting blowpipe an inner nozzle carries a supply of pure oxygen which is used for the actual cutting or burning of the metal. The outer nozzle supplies a mixture of oxygen and acetylene gases which ignite and are used to preheat the work.

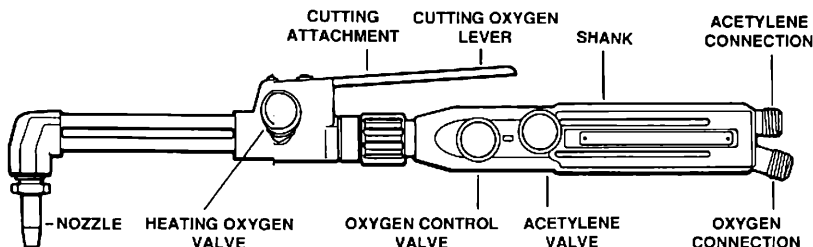


Fig. 16.8 Cutting blowpipe.

When a jet of oxygen is directed on to mild steel or wrought iron which has been preheated to red heat, the metal ignites, thereby providing its own fuel, burns away rapidly, and forms a deposit of iron oxide. The pressure from the jet blows away this deposit, and leaves a clear-cut line in the metal as the blowpipe is moved along. This is because the iron oxide thus formed melts at a lower temperature than mild steel or wrought iron, and due to the intense heat generated by the oxygen, the oxide, in liquid form, is easily blown away out of the path of the cut.

The blowpipe is held at right angles to the work to be cut and the flame applied to the edge farthest away from the operator. When the metal reaches a red heat the cutting oxygen stream is released and the blowpipe moved slowly along the line to be cut.

## **ARC WELDING**

The art of welding metals together by means of electricity is not a new process. Professor Elihu Thomson of America, the father of the art, patented the first practical electric welding machine, which was known as the Jews' Harp Welder, in 1886.

An electric arc is simply a sustained spark between two terminals. In arc welding the spark is formed between an electrode, connected to the welding machine and held in the operator's hand, and the work being welded. When the electrode is scraped on the job sparking occurs, due to the imperfect electrical contact being made. The heat from these sparks ionizes the air in their immediate vicinity and makes it conductive to electricity. If the electrode is now withdrawn slightly the electric current continues to flow across the

gap, through the ionized air, forming an arc.

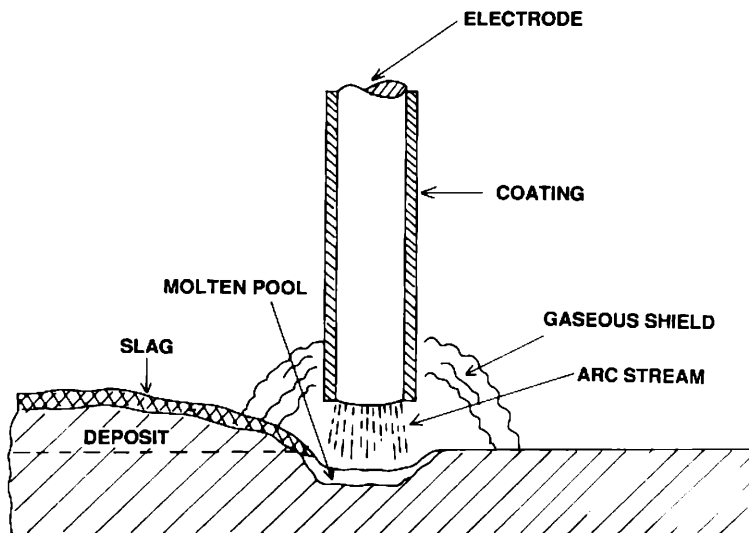
A coated electrode is used. The heat of the arc burns the electrode coating which gives off inert gases. The gases surround the arc and prevent contact between the weld metal and the oxygen and nitrogen of the air. (Fig. 16.9). The coating is consumed at a slower rate than the core wire of the electrode and this causes the end of the coating to project beyond the end of the core wire, thus helping the operator to direct and control his arc. The coating leaves a slight slag on top of the weld which protects the weld metal while cooling. This slag is chipped away when the work has cooled.

Most workshops will have an alternating current supply and therefore a transformer type welding set connected to this supply, with means of adjusting the output to the needs of different jobs, will be used.

To protect the operator's face and eyes from the direct rays of the arc, it is essential that a face mask should be used. These are generally constructed of some kind of pressed-fibre insulating material, dead black in colour to reduce reflection. The shield is fitted with a glass window of such composition as to absorb the infra-red rays, the ultra violet rays, and most visible rays emanating from the arc.

## **INERT GAS SHIELDED WELDING**

In recent years this type of welding has become popular because much higher welding speeds are obtainable than with normal gas or arc welding; consequently there is less heat input to the material being welded and less distortion, which results in production costs being reduced. Although this process is basically for the professional (because



**Fig. 16.9** *How the coated electrode provides the gas shield.*

of the expensive equipment needed) a brief description of the techniques involved should be of interest to all engineers.

The two main types have become known as TIG and MIG welding, the letters standing for Tungsten-inert-gas and Metal-inert-gas respectively. These are fusion welding processes where the weld pool and the arc are enveloped by an inert gas delivered to the weld point through the welding torch or gun. The molten metal is completely shielded from atmospheric contamination. Argon is the gas most commonly used in Britain.

With TIG welding the electrode is not consumed and is not used as a filler metal. Where a filler metal is required a separate welding wire is applied in much the same way as in oxy-acetylene welding.

In the MIG welding process a small

wire is drawn from a reel by electrically driven rollers, into the welding gun held by the welder. This fine wire, between  $\frac{1}{32}$  in. and  $\frac{3}{32}$  in., and of the required composition, is fed at a constant speed through the gun, to an arc maintained between the wire and the work.

During most of the welding processes some sparks and globules of molten metal are thrown out and protection from possible burns is prudent. A leather apron is ideal and stout footwear is desirable.

As stated earlier, welding is a specialised subject, which it is impossible to cover fully in a book of this kind. As is the case with most workshop topics, practical experience is very necessary. Technical Colleges and suppliers of welding equipment run courses on welding techniques and these are highly recommended.

## CHAPTER 17

# HARDENING AND TEMPERING TOOLS

The first step in making a hardened steel tool is to make it dead hard. In this condition it is too brittle to be used and the hardness must be let down to a degree suitable for the job the tool is intended to do. The latter process is known as TEMPERING. There is no need to go into the changes that take place in the structure of the metal during this hardening and tempering process; it is sufficient to say that when cast steel is heated to about 730°C, and kept at that heat for a short period of time, it changes to a hardened state. If it is allowed to cool in the ordinary way it will return to its soft condition. If, however, it is cooled quickly it will remain hard.

As was said earlier, it is impossible to harden mild steel by heating and quenching because of its low carbon content but as the carbon content of the steel increases so the harder it becomes

when heated and rapidly cooled, as the accompanying table shows.

Mild steel can be given a hard outer skin by a treatment known as case-hardening which will be described later.

The tool to be hardened should be heated up slowly at first, bringing it over the initial or black hot stage comparatively slowly so that the steel can adapt itself to the change of form. Once it begins to show signs of changing colour it may be heated more vigorously. Sometimes cracks appear in a tool which has been hardened and this initial careful heating and care taken later not to overheat the steel will go some way in preventing this.

When a forge is used to heat the steel the tool should be turned over and around so as to present all the sides to the heating source so that the heating is constant over that part of the tool which has to be hardened.

TYPE OF STEEL	CARBON CONTENT	EFFECT OF HEATING AND QUENCHING
Mild Medium carbon Medium carbon High carbon	Below 0.25% 0.3 to 0.5% 0.5 to 0.9% 0.9 to 1.3%	Negligible Becomes tougher Becomes hard Becomes very hard

Tools such as chisels and lathe tools only need to be hardened at their cutting edge and with a small margin to allow for sharpening by grinding. When heating this type of tool arrange for that part of the tool where the change from hard to soft takes place to be heated without a sharp demarcation between the red and black hot parts so that when the tool is tempered there is a gradual change from the hard to the soft portion.

The actual temperature at which the steel should be quenched depends upon its composition: for example, Stubs silver steel should be brought to a temperature of 770°C to 790°C while a chromium high carbon alloy steel is hardened at 950°C to 1000°C. In most general workshops there is no means of accurately measuring temperatures so it is a question of judging the temperature by the colour of the heated steel. The hardening heat corresponds to a bright cherry red when viewed in daylight but in shadow. The tool should be kept at this temperature for about half a minute before quenching to allow a thorough transformation to occur.

Another way of judging the correct temperature for hardening is by using a magnet. As the metal is heated it reaches a temperature where it is no longer attracted by a magnet. Test by just touching the tool with the magnet, do not let the magnet get hot or it will be demagnetised. A temperature 60° above the temperature at which this phenomenon occurs will generally be about right for hardening.

Care must be taken when dealing with tools with sharp cutting edges or points not to direct the hot portion of the flame directly at the edge or point for any length of time. Because of their small volume it is very easy to overheat

and burn them so that after hardening and tempering they are very brittle. No amount of re-hardening and tempering will remedy this condition and the defective point or edge must be ground away and a fresh start made.

It is a good idea to keep an old file to find out if the hardening has been successful. If the file will bite into the metal it is certainly not hard and a further attempt at hardening must be made.

Most ordinary cast steel has a mottled grey appearance over all the dead hard parts. This mottling takes the form of almost white or bright patches; the clearer and closer together they are the harder the steel will be.

## TEMPERING

In an ideal situation tools to be hardened are heated in a special furnace which is maintained at a suitable constant temperature as indicated on a high reading thermometer or pyrometer. When tools are made singly or in small quantities, as applies in most workshops, they are heated by a Bunsen burner, blowlamp, gas torch or a small blacksmith's forge with no means of accurately controlling the temperature. However, this is not an insurmountable difficulty.

All steels, hardened or not, which have a bright surface, free from moisture, become coated with an increasing thickness of oxide when heated. This oxide presents varying shades of colour that range from a very pale yellow to a brilliant dark blue. The table shown on p.110 gives the temperatures at which the various colours appear and the tools which can be tempered at each temperature.

It is often not necessary to harden the whole of a tool but only that portion which is required to do the cutting. If



COLOUR	TEMPERATURE DEGREES C	TOOLS
Pale yellow	220°	Hand turning tools and hammer faces
Pale straw	230°	Turning tools
Dark straw	240°	Drills and milling cutters
Brown	250°	Taps
Brownish purple	260°	Punches, reamers, twist drills and rivet snaps.
Purple	280°	Cold chisels
Blue	300°	Springs

this is the case then only that portion required to be hard should be heated and quenched. This leaves a hard cutting portion with a softer but tough shank. Tools such as chisels and punches must not be hardened at the end where they are struck with the hammer. If that end is hard it will be brittle and chips are likely to break off and fly into the face or hands of the operator or anyone standing nearby.

The portion of the tool to be tempered should be polished with emery cloth until it is bright so that the tempering colours can be clearly seen. When the appropriate colour appears the tool is quenched.

Clean water is an effective coolant but it can be improved by adding salt,  $\frac{3}{4}$ lb to a gallon of water. The tool should be immersed in the coolant vertically and point downwards and with a moderate up and down movement. It must not be quenched in a horizontal position as it may contract more on one side than the other, causing cracking.

For some tools, such as chisels and punches, the one heat method of heating and quenching, used by blacksmiths, may be used. The tool is heated to the hardening temperature for about half its length and then the cutting edge

is quenched for a length of about 30 to 60 mm. When it is quite certain that this quenching is complete the tool is removed from the water and the cutting edge polished with a piece of a broken emery wheel, or if this is not available with a strip of emery cloth nailed to a piece of wood. The heat from the unquenched portion will travel, by conduction, to the cutting edge and the tempering colours will appear. When the required colour appears the whole tool must be quenched. This method gives a tool hardened at its cutting edge with the metal gradually decreasing in hardness towards the shank, leaving the end soft where it is struck by the hammer.

Like all workshop jobs actual experience is far better than the written word and beginners are advised to practise until they master the technique. Unlike most workshop jobs, if a mistake is made in hardening and tempering the tool is not spoilt. It can be re-hardened and tempered to remedy any error which has made at the first attempt.

### CASE HARDENING

Case-hardening is employed on iron and mild steel which cannot be hardened by heating and quenching

because of its low carbon content. It does not take the place of real hardening because only the surface is hardened for a small depth, in other words, it imparts a hard skin to the steel while the centre remains soft. Obviously it is not a suitable medium for a cutting tool which has to be sharpened, because the case-hardening would be ground away. Its main use is to superficially harden the wearing surfaces of such items as pins and journals so that they resist wear but at the same time retain the greater part of their toughness.

Ideally the objects to be case-hardened are packed into cast iron or steel boxes and covered all over with a substance rich in carbon such as charcoal granules, hoof clippings, bone dust

or charred leather. The boxes and their contents are then placed in a furnace at a temperature of about 900° to 950°C for some hours. Following the heating the boxes are opened while hot and the steel pieces dipped into the quenching bath, usually containing cold water.

It is unlikely that the amateur will be able to use this method but good results can be obtained by using one of the trade products. 'Kasenit' is a very well known one sold in powder form.

To case-harden small parts some of the powder is heaped on to a metal tray. The job is heated to a yellow heat and then rolled in the powder. This is repeated two or three times and then the component is again heated and finally quenched.

## CHAPTER 18

# KEYS, KEYWAYS, SPLINES, COLLARS AND SHAFTS

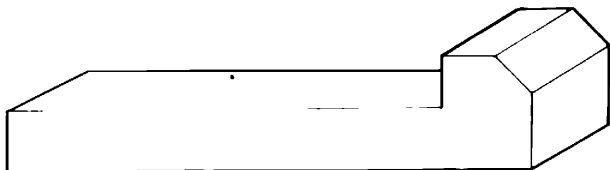
In engineering parlance a **KEY** is a component used to locate and secure an object in position. In its most common form it is used to position a pulley or wheel on a shaft and to ensure that they rotate together at the same speed.

In addition to securing a wheel to a shaft the key has also to take the shear stress when the wheel is turned and the turning effort of the wheel has to be transmitted to the shaft. In other cases the shaft is driven and the key has to take the drive to the pulley. Because of this shear stress the key must be a good fit and bear evenly on all faces of the wheel boss **KEYWAY** (that is the recess in which the key fits) and in the shaft keyway. If the key is a poor fit the shear stress is transmitted only by the parts which are in close contact instead of the whole area. The wheel will soon begin to rock on the shaft and rapid wear will occur both on the key and the keyway.

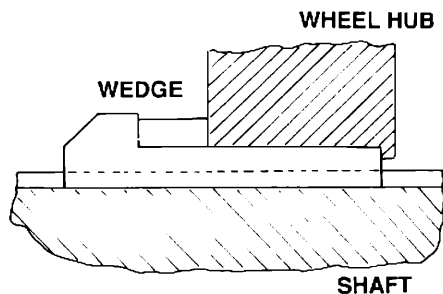
The **GIB HEAD KEY**, illustrated in Fig. 18.1, is rectangular in section and the top face has a taper of approximately 1 in 64, but its sides are parallel.

When a key of this type has to be removed a wedge is driven between the head of the key and the wheel hub, (see Fig. 18.2a). On the rare occasions the back end of the key is accessible a drift may be used to drive the key out as is shown in Fig. 18.2b.

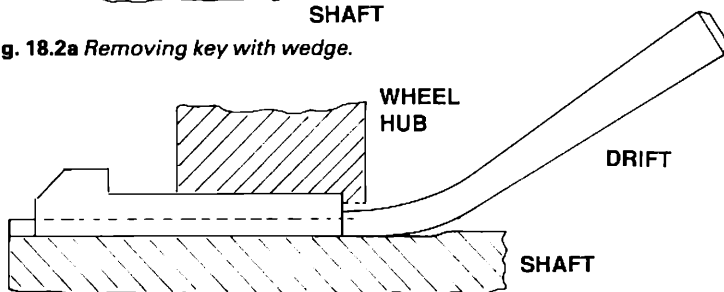
When fitting a key its sharp corners should be filed off as these give a false impression that the key is fitting tightly. The key is then filed so that it is a nice sliding fit, without shake, in the keyways. The point of the key is then filed down for a short distance until it will just enter the two keyways when the wheel is on the shaft. This gives a rough indication of the depth of the key. The filed down portion should then be carefully measured with a micrometer. The



**Fig. 18.1** *Gib Head key.*

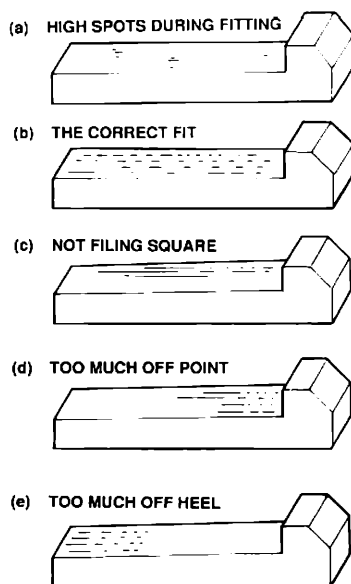


**Fig. 18.2a** Removing key with wedge.

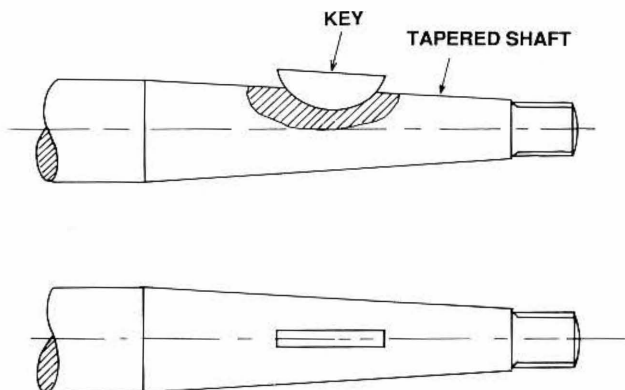


**Fig. 18.2b** Removing key with drift.

top of the key is then filed down until the part near the head is a few 'thou' wider than the micrometer reading. The sharp corners are again removed and the key tried in the position it will eventually occupy. It is gently driven in position, removed, and the top inspected for friction marks, which will show clearly where it is touching the top of the wheel keyway. These friction spots are carefully removed with a scraper and the key again inserted in position. This process is repeated until the whole area of the top of the key shows compression streaks covering practically the whole surface. Fig. 18.3a shows the key with high spots during fitting, 18.3b the ideal fit, and 18.3c a fault produced by not filing square across the top of the key. Filing too much off the point of the key or at the opposite end will give the marks depicted in Figs. 18.3d and 18.3e. Mark-



**Fig. 18.3**

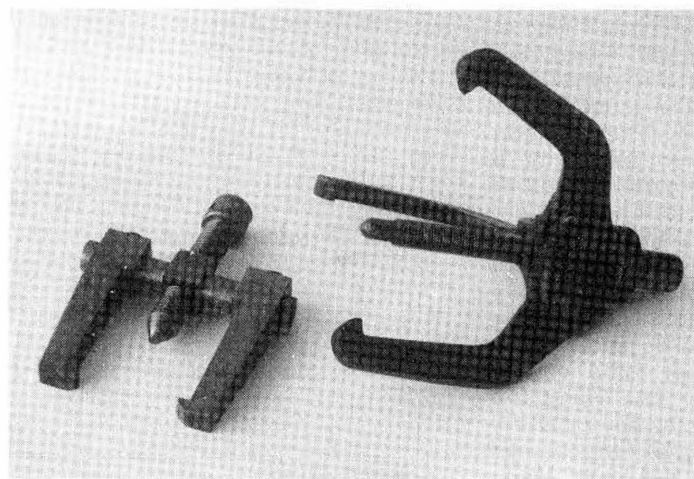


**Fig. 18.4** Woodruff key.

ing blue may be used to make the marks where the key is bearing more easily seen.

**The Woodruff Key** is completely different from the Gib Head key already described. Its side view is the minor segment of a circle but it is of even width and thickness. The curved part

fits into a similarly shaped recess in the shaft. It is used chiefly on tapered shafts as shown in Fig. 18.4. The hub of the wheel has a similar taper to the shaft. The shaft end is usually threaded and fitted with a nut and washer so that when the nut is tightened the boss grips the shaft firmly with a wedging action so that the key is relieved of shear



**Fig. 18.5** Two and three leg wheel-pullers.

stress. There must always be clearance between the top of the key and the keyway in the wheel, since if this were not so the key would prevent the hub being tightly wedged on to the shaft.

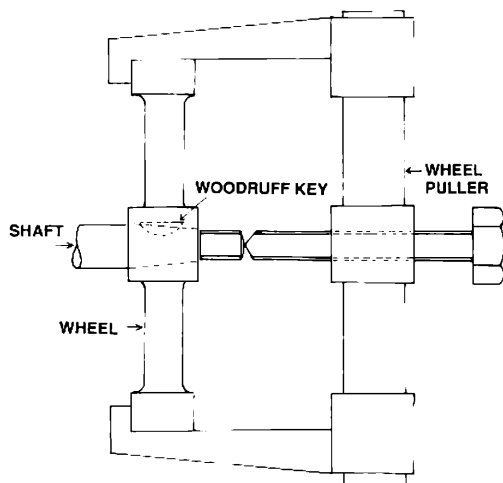
The keyway on the shaft is machined with a special cutter in a milling machine, a process which is outside the scope of this book, but bench workers may be required to make the key. The key is cut from a piece of round steel of a diameter to match the curve of the key and then filed so that it is a nice fit in the keyways, remembering that clearance must be maintained between the top of the key and the keyway in the wheel.

The removal of a wheel fitted to a tapered shaft is often difficult, especially if it has been in position for a long time. Generally the wheel is so firmly fixed that it can only be removed with the aid of a wheelpuller. These are of many different types: one with three legs and another with two are shown in Fig. 18.5. The pull exerted by the legs of the puller should be as near the hub of

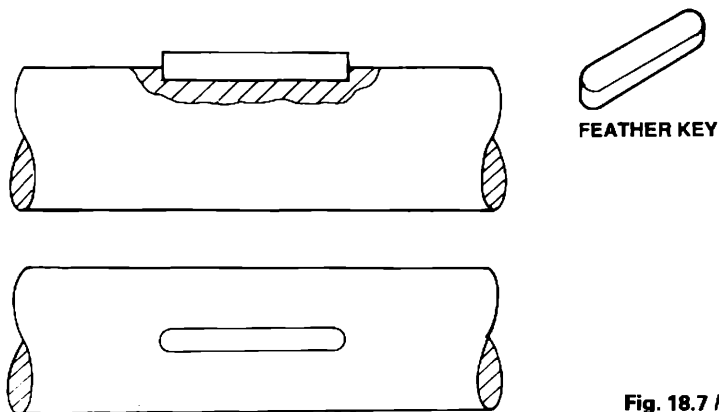
the wheel as possible. Pulling on the rim, as shown in Fig. 18.6, often cannot be avoided, but this puts a big strain on the wheel and makes the puller less effective than if the legs were nearer the hub. In some cases tapped holes are provided in the wheel for the attachment of the puller. When tightening the screw of the puller does not remove the wheel a smart hammer blow to the head of the screw will often have the desired result. The sudden jar of the hammer blow causes the tightly wedged taper to break away while the steady pull of the wheel-puller fails to do so.

Woodruff keys are sometimes used on parallel shafts where the load is light but in that situation the key has to resist shear stress as there is no wedging action between the shaft and the wheel.

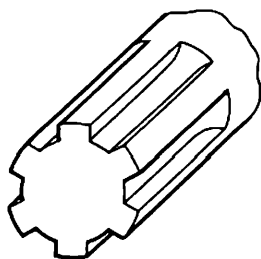
**A feather key**, Fig. 18.7, is of rectangular section, usually with rounded ends. It is sunk for about half its depth into the shaft and its sides and ends fit snugly



**Fig. 18.6** Removing wheel with wheel puller.

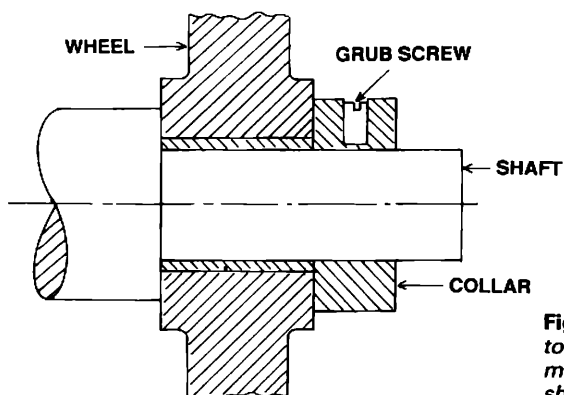


**Fig. 18.7** Feather key.



**Fig. 18.8** Splined shaft.

all around the keyway. It is used where clutches, gears and other details are required to slide along a shaft. It is often necessary to allow this sliding movement in order to permit a wheel to engage with another gear-wheel parallel to it. The keyway on the shaft will have been machined on a milling machine but the key may have to be made at the bench. The wheel must be free to slide on the shaft, so the key must therefore be a sliding fit in the wheel keyway and a snug fit in the shaft



**Fig. 18.9** Collar fitted to prevent wheel moving endways on shaft.

and there must be clearance between the top of the key and the hub keyway. Sometimes this type of key is held in the shaft by countersunk screws.

**Splined shafts** provide a similar side-ways movement for a wheel carried on them to that described for a feather key. The shaft has rectangular recesses all around its circumference and the wheel hub is similarly shaped. Splines are used extensively in all types of gear-boxes where the various gear ratios are

obtained by sliding gearwheels along shafts to mesh with other wheels. See Fig. 18.8.

In some cases 'V' shaped splines are used to prevent a wheel from turning on a shaft. Steering wheels on motor cars, for example, are generally fitted to the steering column in this way.

To prevent a wheel fitted freely on a shaft from moving sideways a COLLAR, Fig. 18.9 is used. It consists of a plain ring fitted with a grub screw to hold it firmly on the shaft.



## CHAPTER 19

# SHEET METALWORK

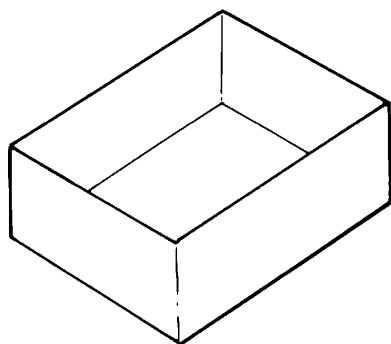
Sheet metalwork is the province of skilled tradesmen – the silversmith, tinsmith and panel beater – but on occasions the general engineer will be called upon to make articles using sheet metal. This is particularly the case with model engineers; locomotive cabs, tenders and boilers are all fashioned from sheet brass and copper.

In the tinsmith's shop many special tools and machines are employed and it is unlikely that these will be available to the model engineer or in the fitting

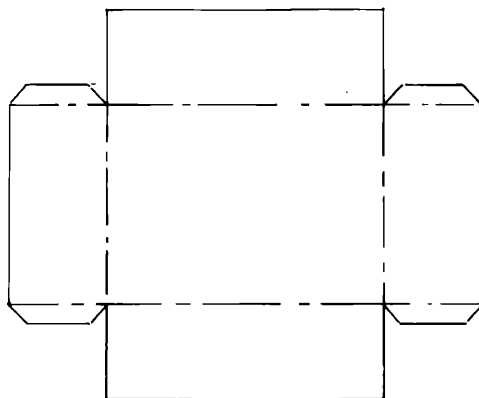
shop but much can be achieved by improvisation and with simple tools.

The metals used may be tinplate, black, bright or galvanised iron, copper, brass or aluminium or the precious metals, i.e. silver or gold, although it is unlikely that the latter will be found in the ordinary shop.

The thickness of sheet metals may be given in STANDARD WIRE GAUGE (SWG) or in metric or Imperial measure. The following table shows some of the corresponding sizes.

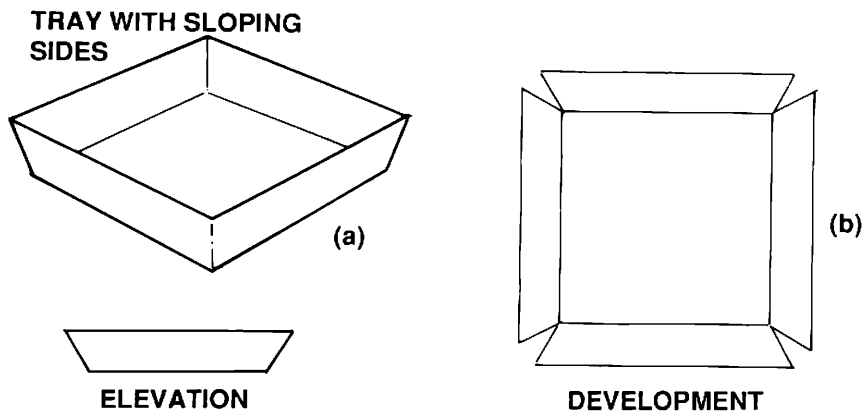


**SHEET METAL BOX**



**DEVELOPMENT OF BOX**

**Fig. 19.1**

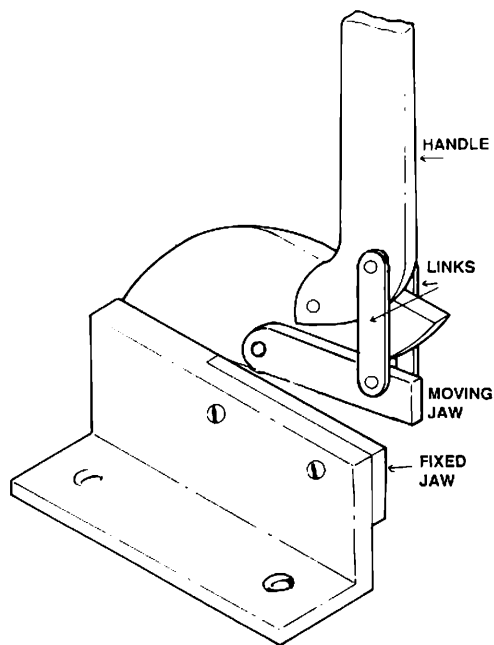


**Fig. 19.2** Development of tray with sloping sides.

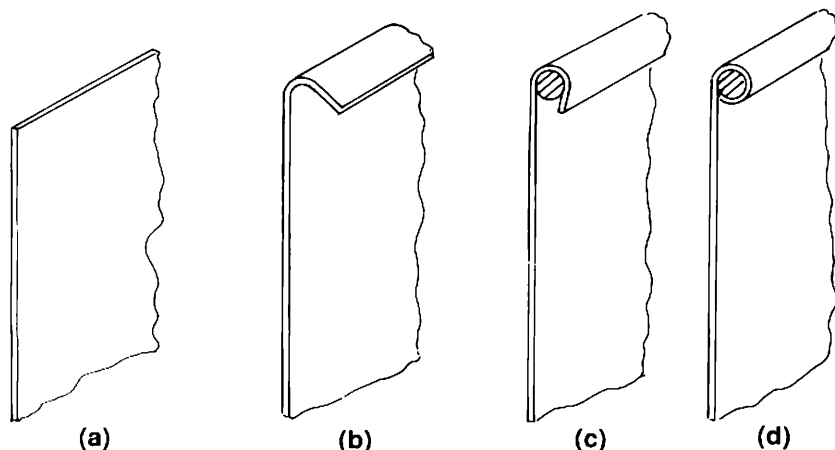
SWG	mm	Inch
22	0.7	0.028
20	0.9	0.033
18	1.2	0.048 (approx. $\frac{1}{4}$ in.)
16	1.6	0.064 (approx. $\frac{1}{16}$ in.)
13	2.5	0.092 (approx. $\frac{1}{32}$ in.)

When a shape is being marked out on a thin metal, so that when cut out and folded up it forms a complete article, it is said that the surface of the object has been **DEVELOPED**. Fig. 19.1 shows the development of a sheet metal box. Flaps have been added to the development to enable the sides to be fastened together.

Often the true shape of the surface is not shown directly on the drawing from which the development is to be made. Fig. 19.2a shows a tray with sloping sides, and the exact shapes of the sides are not shown on the drawing. It is imagined that the sides are swung down to the horizontal plane and then projected on to the bottom of the tray as shown in Fig. 19.2b. Before actually cutting out the developed shape on the metal it is often useful to do this on thin



**Fig. 19.3** Bench shears.

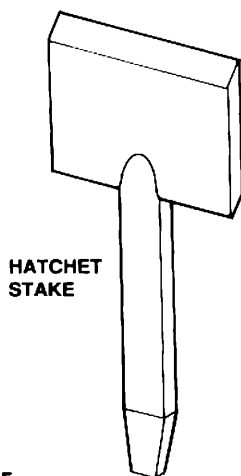


**Fig. 19.4** Stages in the formation of a wired edge.

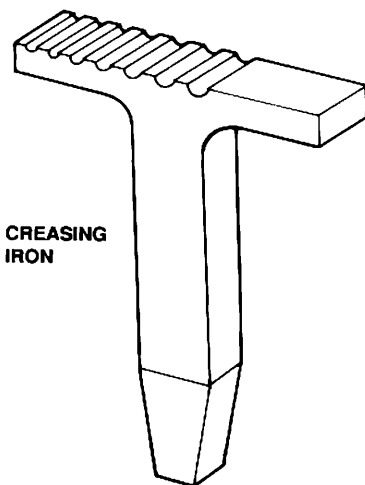
card. This will show up any errors without spoiling valuable material.

Sheet metal is usually cut with *bench shears*, Fig. 19.3, or *tinman's snips*, which resemble very heavy scissors. They are made in a variety of forms, some specially made for cutting curves. In the tinsmith's shop foot-operated *guillotines* may be available and these

machines give a very clean straight cut. Bench shears and guillotines are designed to slice through sheet steel with ease. Because of their power they are also capable of inflicting serious injury if improperly used. Make sure you fully understand how to operate them and never use them without the appropriate guard in position.



**HATCHET  
STAKE**



**CREASING  
IRON**

**Fig. 19.5**

**Annealing** is a heat treatment applied to metals in order to restore or increase their malleability. When a metal is worked from one shape to another, whether it be by rolling, stretching, pressing or flanging, it becomes harder under the process and is less malleable. In some cases the metal will become so brittle that it will fracture if the annealing process is neglected. Copper is particularly prone to this work-hardening, as makers of model engine boilers will readily testify.

Generally annealing is accomplished by heating the metal to a dull red and then allowing it to cool. Sometimes copper is plunged into cold water after heating and although this is a time-saver and does not affect the annealing process, it may cause distortion. If there is any risk of this occurring it is better to let the copper cool naturally.

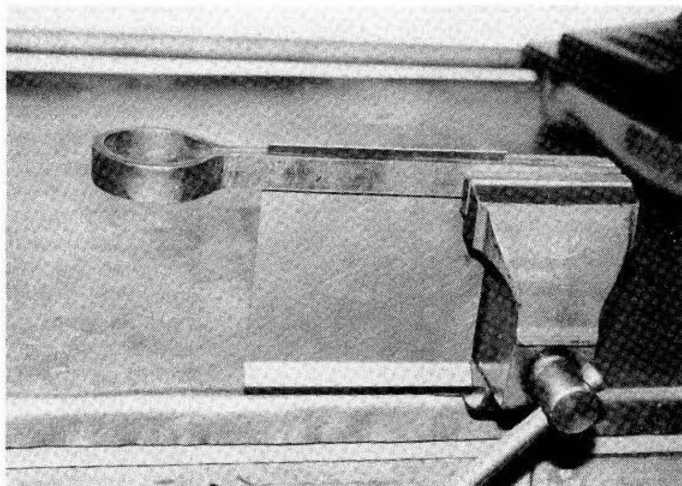
Very often a sheet metal article has its edge bent over a wire so as to enclose and strengthen it. This conceals the raw sharp edge which might prove a source



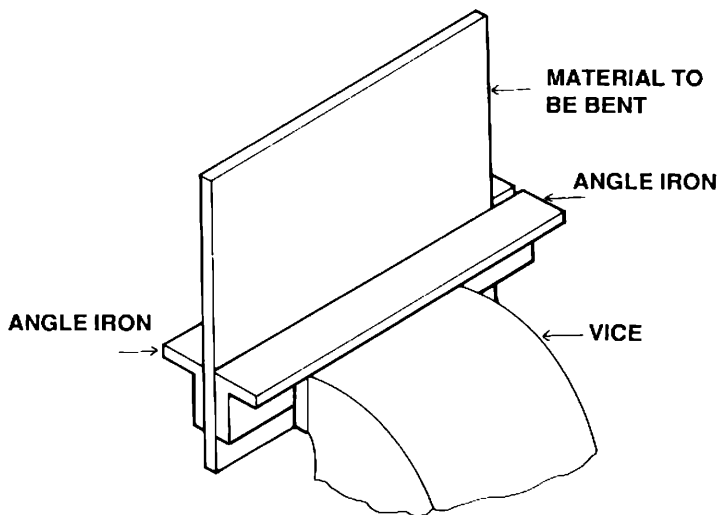
**Fig. 19.6** *Folding iron forged from  $\frac{5}{16}$ "  $\times$  1" mild steel.*

of danger. Fig. 19.4 shows the various stages in the formation of an edge of this kind.

The sheet-metal worker uses STAKES of various kinds, two of which are shown in Fig. 19.5. These are inserted in a special fixture on the bench. They are used, for example, to insert the wire in the edge of sheet metal, as illustrated in Fig. 19.4. Fig. 19.4a shows the elevation of the metal to be wired, (b) the wiring allowance after being bent over the hatchet stake by a mallet, and (c) the metal bent over the wire; in this operation the work would be supported on the creasing iron. (d) shows the wired edge with the metal tucked neatly over the wire so as to enclose it completely.



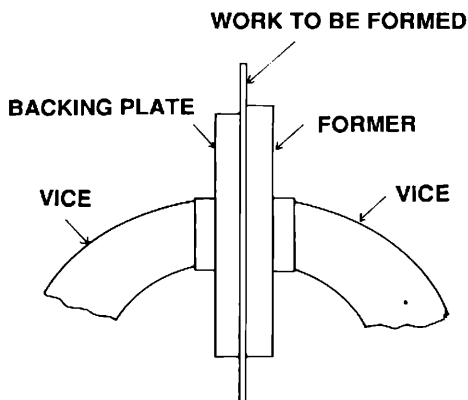
**Fig. 19.7** *Folding iron held in vice to secure a piece of sheet metal in which a 90° bend is required.*



**Fig. 19.8** Angle iron used for bending.

The stakes are like miniature, specially shaped anvils and if they are not available much can be done by utilising pieces of steel of similar shapes, held in the vice.

A useful tool for holding sheet metal



**Fig. 19.9** Set-up for forming work.

is the folding iron shown in Fig. 19.6, which is quite simple to make in the workshop if a forge or some other source of heat is available. Fig. 19.7 shows the folding iron held in the vice securing a piece of 20 SWG sheet metal which is to be bent over at a right angle.

Two pieces of angle iron, held in the vice, as shown in Fig. 19.8, can be used instead of a bending iron but this makes the job more difficult to line up.

**Bending allowance.** When sheet metal is bent the outside of the bend becomes stretched and the inside compressed. Somewhere in the centre of the bend there is a point where the metal is neither stretched or compressed. This is said to be about 0.4 times the thickness of the metal from the inside radius. If, therefore, a little under half the thickness of the metal is allowed for the bend, it should not be far out.

**Flanging and Forming.** Makers of model engine boilers are very familiar with this technique. Basically it consists of making a **FORMER** over which the work is beaten into shape. Hardwood can be used for formers on which to flange copper up to about  $\frac{1}{2}$  in. thick. Metal formers can be used, and although these are more durable, they are more difficult to make. The former must have the same dimension as the finished job, minus twice the thickness of the metal being used. The edge of the former over which the metal will be formed must be radiused and not left sharp.

A **Backplate**, although not essential, is helpful, the copper forming the filling of

a sandwich between the former and the backplate. See Fig. 19.9.

The copper must be annealed and then placed, in the correct position, between the former and the backplate. The three are then secured in the vice and the edge of the copper tapped with a hardwood mallet.

The copper, when properly annealed, will feel soft and dead when it is hit. As soon as it begins to work-harden the dead feeling will disappear. *This is the time to again anneal the copper.* If it is delayed there is a risk of the copper cracking. The whole success of the job depends on annealing as soon as it becomes necessary, however frequent this may be.

# APPENDIX

Weight of castings – weigh pattern and multiply weight by factor under appropriate material. If applicable calculate core weight similarly and deduct.

Weight of solid sections – weights are in pounds per inch length. Multiply appropriate cross-section dimensions, multiply product

by relevant table figure. (Divide result by 5.58 for approx. kg/cm weight.)

Gauges (opposite) – some are obsolete or used only in specialised trades, but may still be encountered; Imperial measure is normal but conversion of thickness or diameter to metric is straightforward.

ESTIMATING APPROXIMATE WEIGHT OF CASTINGS

PATTERN MATERIAL	ALUMINIUM OR LIGHT ALLOY	MAGNESIUM ALLOY (ELEKTRON)	BRASS	CAST IN—				
				CAST IRON	COPPER	ZINC ALLOY	SOLDER	LEAD
BAYWOOD	3.2	2.1	9.9	8.8	10.5	8.5	11.1	13.5
BEECH ...	3.1	2.0	9.5	8.5	10.1	8.2	10.8	13.1
CEDAR ...	5.8	.38	18.1	16.1	19.2	15.6	20.2	24.5
CHERRYWOOD	3.9	2.6	12.0	10.7	12.8	10.4	13.6	16.5
MAHOGANY	3.1	2.0	9.5	8.5	10.1	8.2	10.8	13.1
MAPLE ...	3.2	2.1	10.3	9.2	11.0	8.9	11.1	13.5
OAK ...	3.4	2.25	10.5	9.4	11.2	9.1	11.85	14.3
WHITE PINE	5.3	3.5	16.5	14.7	17.5	14.3	18.5	22.4
WHITEWOOD	5.9	3.9	18.4	16.4	19.5	15.9	20.6	25.0
YELLOW PINE	4.7	3.1	14.7	13.1	15.6	12.7	16.4	19.8

WEIGHTS OF VARIOUS SOLID SECTIONS IN DIFFERENT MATERIALS  
(Weights in pounds per inch length)

MATERIAL	SECTION: a width; b height; d diameter (inscribed) h altitude (.....)					
	SQUARE a x a Times	RECT- ANGLE a x b Times	CIRCLE d x d Times	TRIANGLE a x h Times	HEXAGON d x d Times	OCTAGON d x d Times
ALUMINIUM ...	.1015	.1015	.08	.0508	.087	.083
ALUMINIUM BRONZE ...	.293	.293	.23	.147	.254	.243
BRASS ...	.307	.307	.242	.154	.266	.254
BRONZE ...	.308	.308	.242	.154	.267	.255
COPPER ...	.318	.318	.25	.159	.276	.264
DURAL ...	.0115	.1015	.08	.0508	.087	.083
GUNMETAL ...	.310	.310	.244	.155	.269	.257
IRON, CAST ...	.260	.260	.205	.130	.226	.215
IRON, WROUGHT ...	.283	.283	.223	.142	.245	.235
LEAD ...	.410	.410	.322	.205	.355	.340
MAGNESIUM ...	.063	.063	.05	.032	.0556	.052
MAGNESIUM ALLOY ...	.065	.065	.051	.033	.056	.054
LIGHT ALLOY (MG) ...	.095	.095	.075	.048	.824	.079
PHOSPHOR BRONZE ...	.320	.320	.250	.160	.277	.265
MONEL ...	.320	.320	.250	.160	.277	.265
STEEL ...	.283	.283	.223	.142	.245	.235
TIN ...	.263	.263	.208	.132	.228	.218
SOLDER ...	.34	.34	.268	.170	.294	.282
TUNGUM ALLOY ...	.304	.304	.240	.152	.264	.252
ZINC ...	.253	.253	.20	.127	.219	.210

**WIRE AND SHEET GAUGES**  
(All Dimensions in Inches)

Gauge No.	U.S. Standard Gauge										U.S. Standard (Revised) U.S.S.G.			Gauge No.
	Imperial Standard Wire Gauge (S.W.G.)	U.S. Steel Wire Gauge (Std. W.G.) Washburn & Moen (W. & M.) Ruebbling Gauge	Brown & Sharpe Gauge (B x SG) American Wire Gauge (A.W.G.)	(American) Music Wire Gauge	Birmingham Wire Gauge (B.W.G.) Stubbs Iron Wire Gauge	Birmingham Gauge (B.G.)	U.S. Standard Sheet Metal Gauge (U.S. Std.)	Thickness Decimal	Thickness Inch Fraction	Approx. Thickness	Weight oz./sq. ft.			
7/0	.500	.4900	—	—	—	.6666	.4902	.5	—	—	—	7/0		
6/0	.464	.4615	.5800	.004	—	.6250	.4596	.46875	15/32	—	—	6/0		
5/0	.432	.4305	.5165	.005	.500	.5883	.4289	.4375	7/16	—	—	5/0		
4/0	.400	.3938	.4600	.006	.454	.5416	.3983	.40625	13/32	—	—	4/0		
3/0	.372	.3625	.4096	.007	.425	.5000	.3676	.375	—	—	—	3/0		
2/0	.348	.3310	.3648	.008	.380	.4452	.3370	.34375	11/32	—	—	2/0		
0	.324	.3065	.3249	.009	.340	.3964	.3064	.3125	5/16	—	—	0		
1	.300	.2830	.2893	.010	.300	.3532	.2757	.28125	9/32	—	—	1		
2	.276	.2625	.2576	.011	.284	.3147	.2604	.265625	17/64	—	—	2		
3	.252	.2437	.2294	.012	.259	.2804	.2451	.25	—	.2391	.160	3		
4	.232	.2253	.2043	.013	.238	.2500	.2298	.234375	15/64	.2242	.150	4		
5	.212	.2070	.1819	.014	.220	.2225	.2145	.21875	7/32	.2092	.140	5		
6	.192	.1920	.1620	.016	.203	.1981	.1991	.203125	13/64	.1943	.130	6		
7	.176	.1770	.1443	.018	.180	.1764	.1838	.1875	3/16	.1793	.120	7		
8	.160	.1620	.1285	.020	.165	.1570	.1685	.171875	11/64	.1644	.110	8		
9	.144	.1483	.1144	.022	.148	.1398	.1532	.15625	5/32	.1494	.100	9		
10	.128	.1350	.1019	.024	.134	.1250	.1379	.140625	9/64	.1345	.90	10		
11	.116	.1205	.09074	.026	.120	.1113	.1225	.125	—	.1196	.80	11		
12	.104	.1055	.08081	.029	.109	.0991	.1072	.109375	7/64	.1046	.70	12		
13	.092	.0915	.07196	.031	.095	.0882	.0919	.09375	5/32	.0897	.60	13		
14	.080	.0800	.06408	.033	.083	.0785	.0766	.078125	5/64	.0749	.50	14		
15	.072	.0720	.05707	.035	.072	.0699	.0689	.0703125	9/128	.0673	.45	15		
16	.064	.0625	.05082	.037	.065	.0625	.0613	.0625	1/16	.0598	.40	16		
17	.056	.0540	.04526	.039	.058	.0556	.0551	.05625	9/160	.0538	.36	17		
18	.048	.0475	.04030	.041	.049	.0495	.0496	.05	1/20	.0470	.32	18		
19	.040	.0410	.03589	.043	.042	.0440	.0429	.04375	7/160	.0418	.28	19		
20	.036	.0348	.03196	.045	.035	.0392	.0368	.0375	3/80	.0359	.24	20		
21	.032	.0318	.02846	.047	.032	.0349	.0337	.034375	11/320	.0329	.22	21		
22	.028	.0286	.02535	.049	.028	.0312	.0306	.03125	1/32	.0299	.20	22		
23	.024	.0258	.02257	.051	.025	.0278	.0276	.028125	9/320	.0269	.18	23		
24	.022	.0230	.02010	.055	.022	.0248	.0245	.025	1/40	.0239	.16	24		
25	.020	.0204	.01790	.059	.020	.0220	.0214	.021875	7/320	.0209	.14	25		
26	.018	.0181	.01594	.063	.018	.0196	.0184	.01875	3/160	.0179	.12	26		
27	.0164	.0173	.01420	.067	.016	.0174	.0169	.017875	11/640	.0164	.11	27		
28	.0148	.0162	.01264	.071	.014	.0156	.0153	.015625	1/64	.0149	.10	28		
29	.0136	.0150	.01126	.075	.013	.0139	.0138	.0140625	9/640	.0135	.9	29		
30	.0124	.0140	.01003	.080	.012	.0123	.0123	.0125	1/80	.0120	.8	30		
31	.0116	.0132	.008928	.085	.010	.0110	.0107	.0109375	7/640	.0105	.7	31		
32	.0108	.0128	.007950	.090	.009	.0098	.0100	.01015625	13/1280	.0097	.65	32		
33	.0100	.0118	.007080	.095	.008	.0087	.0092	.009375	3/320	.0090	.6	33		
34	.0092	.0104	.006305	.100	.007	.0077	.0084	.00859375	11/1280	.0082	.55	34		
35	.0084	.0095	.005615	.106	.005	.0069	.0077	.0078125	5/640	.0075	.5	35		
36	.0076	.0090	.005000	.112	.004	.0061	.0069	.00703125	9/1280	.0067	.45	36		
37	.0068	.0085	.004453	.118	—	.0054	.0065	.006640625	17/2560	.0069	4.25	37		
38	.0060	.0080	.003965	.124	—	.0048	.0061	.00625	1/160	.0060	.4	38		
39	.0052	.0075	.003531	.130	—	.0043	.0057	—	—	—	—	39		
40	.0048	.0070	.003145	.138	—	.0039	.0054	—	—	—	—	40		
41	.0044	.0066	.002800	—	—	.0034	.0052	—	—	—	—	41		
42	.0040	.0062	.002494	—	—	.0031	.0050	—	—	—	—	42		
43	.0036	.0060	.002221	—	—	.0027	.0048	—	—	—	—	43		
44	.0032	.0058	.001978	—	—	.0024	.0046	—	—	—	—	44		
45	.0028	.0055	.001761	—	—	.0022	—	—	—	—	—	45		
46	.0024	.0052	.001568	—	—	.0019	—	—	—	—	—	46		
47	.0020	.0050	.001397	—	—	.0017	—	—	—	—	—	47		
48	.0016	.0048	.001244	—	—	.0015	—	—	—	—	—	48		
49	.0012	.0046	.001108	—	—	.0014	—	—	—	—	—	49		
50	.0010	.0044	.000986	—	—	.0012	—	—	—	—	—	50		



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I am particularly indebted to my son David, a professional engineer, for his encouragement and help throughout the writing of this book and for reading and correcting the original script.

Finally I dedicate this book to my wife, Irene, who gave me all her help and support. Unfortunately she did not live to see the book completed.

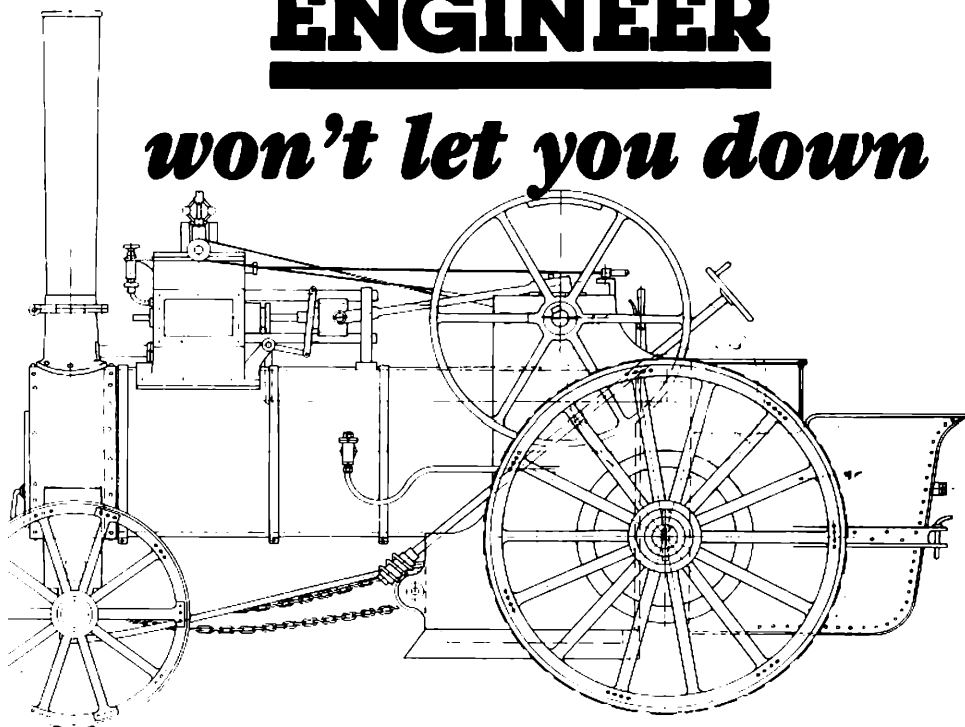
*The publishers regret to report that Les Oldridge survived his wife for only a very brief time and died shortly after submitting the manuscript and illustrations for this book.*

Adhesives	99	Non-ferrous metals	11
Arc welding	106	Orthographic projection	14
Bench	6	Oxy-acetylene-welding	101
Brazing	98	Plastics	13
Bronze welding	98	Pliers	77
Case hardening	110	Projection, drawing	15
Chisels	33	Properties of metals	8
Clamps, vice	7	Punches	36
Collars	116	Reading drawings	14
Cutting metal with oxy-acetylene	105	Reamers	67
D-bits	67	Rightward welding	104
Dies	84	Riveting	86
Draw filing	30	Safety	6
Drills	58, 81	Scrapers and scraping	39
Engineering drawings	14	Screwdrivers	76
Engineers' blue	40	Screwed fastenings	69
Feather key	115	Screw threads	71, 79
Ferrous metals	10	Sheet metalwork	118
Files and filing	25	Soldering, silver	97
First angle projection	18	Soldering, soft	91
Fluxes	92, 97	Spanners	75
Hacksaws	22	Splines	117
Hammers	32	Steels	10
Hardening and tempering tools	108	Surface plate	40
Holder for round bar	7	Symbols, drawing	18
Identification of ferrous metals	12	Taps	79
Keys and keyways	112	Tempering	109
Leftward welding	104	Third angle projection	18
Marking out	53	Threads	81
Materials	8	Types of file	27
Measuring	44	Vernier caliper reading	51
Micrometer reading	50	Vice clamps or clams	7
		Welding	100
		Woodruff key	114

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## 18. Basic Benchwork

A considerable amount of engineering work takes place on the bench, using hand tools and techniques which are second nature to those who earn their living in an engineering environment; they probably learned at a technical college, as an apprentice, or possibly by the example of older and more experienced workmates.

The amateur engineer or hobbyist may not have enjoyed such advantages and, for example, may break a lot of hacksaw blades because he has not been shown how to use the saw or what sort of blades he should be using. This book sets out to cover all the normal bench processes in a simple but informative manner which should help all who have come to enjoy working with metals but whose education did not include a grounding in the basics of engineering benchwork.

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